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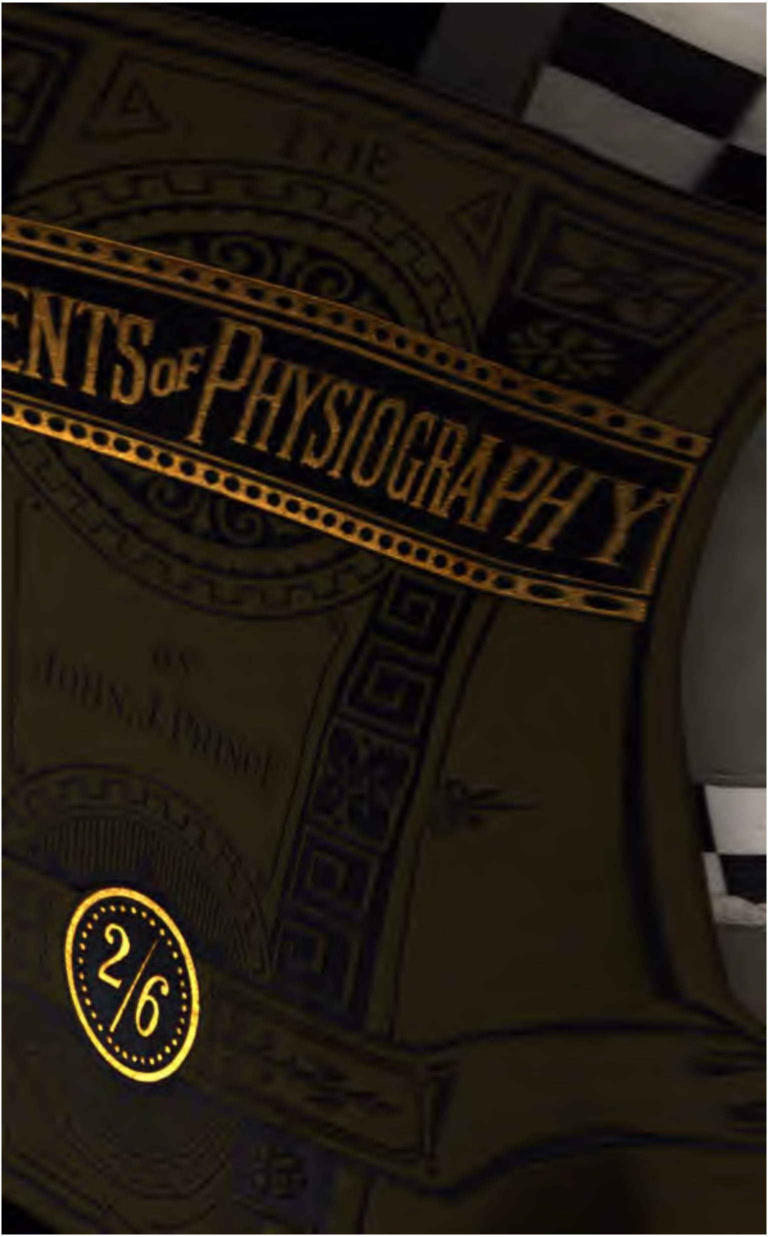

THE

ENTS OF PHYSIOGRAPHY

BY

JOHN J. PRINCE

2/6

THE ELEMENTS

OF

PHYSIOGRAPHY.

FOR THE USE OF

SCIENCE CLASSES, ELEMENTARY AND MIDDLE-CLASS SCHOOLS,
AND PUPIL TEACHERS.

BY

JOHN J. PRINCE,

Author of "School Management and Method," etc., etc.

SIXTH EDITION.—REVISED AND GREATLY ENLARGED.

JOHN HEYWOOD,
DEANSGATE AND RIDGEFIELD, MANCHESTER;
AND 11, PATERNOSTER BUILDINGS,
LONDON.
1885.

23. f. 14.

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PREFACE.

THIS little work has been prepared with especial reference to the Syllabus for the Elementary Stage of Physiography—recently issued by the Science and Art Department—but not confined to it. It is hoped that it will be found useful to all who wish to inquire into the physical features of the earth, its atmosphere, &c. No effort has been spared to render it accurate up to the information of the present day.

To the student, I would say, to obtain a thorough knowledge of the configuration of the earth's surface, the superficial conformation of the ocean, the currents thereof, and the course, tributaries, and water-partings of rivers, nothing short of a *very careful* study of political and physical maps (many good ones can be procured from the publisher of this present work) will enable him to succeed.

1877. J. J. P.

PREFACE TO THE SIXTH EDITION.

THE present edition has been thoroughly revised, and much enlarged, embracing the whole of the Advanced Stage as well as the Elementary. Again no effort has been spared to bring it up to the information of the present day.

1885. J. J. P.

CONTENTS.

PART I.

PHYSICS:

OR, NATURE'S FORCES AND THEIR MEASUREMENTS.

PAGE.

Definition—Units of Time—Space—Mass—Metric System—Velocity—Force (composition and measurement of)......... 7

Composition and Resolution of Forces—Parallelogram and Polygon of Forces—Velocities.. 9

Matter.—Compressibility—Gravitation—Cohesion—Chemical Affinity—Heat—Energy produced by Heat, Electricity, &c. 12

Electricity and Magnetism.—Electricity—Electrical Disturbances—Atmospheric Electricity—Accumulation in the Clouds—Lightning—Thunder—Magnetism 19

Terrestrial Magnetism and Electricity.—The Earth a Magnet—Mariner's Compass—Magnetic Elements—Magnetic Storms—Aurora Borealis 23

CHEMICAL ELEMENTS.

Chemical Action—Compounds—The Chemical Elements—Character of Atomicity—Binary Compounds—Terms—Compounds Broken Up—Decomposition of—Rock-forming Minerals—Granite—Composition of the Earth's Crust...... 26

Water.—Composition of—Expansion of—Different States—Latent and Specific Heat 37

GEOLOGY RELATING TO THE CRUST OF THE EARTH.

Rocks.—Sedimentary—Stratified—Mechanically, Organically, and Chemically Formed—Surface Soil—Metamorphic—Unstratified—Plutonic 40

Internal Heat of the Globe.—The Interior of the Earth—Phenomena and Distribution of Volcanoes—Hot Springs—Earthquakes—Earthquake Bands—Causes of Earthquakes and Volcanoes—Effect 51

Crust of the Earth.—Upheaval and Subsidences—Relative Age of Strata—Changes of the Earth's Surface and in the Forms of Life—The Different Systems—Glacial Period—The Age of the Earth.................................. 61

PHYSICAL GEOGRAPHY.

PAGE.
THE SURFACE OF THE EARTH.—Definitions 68

EXTENT AND DISTRIBUTION OF LAND AND WATER.

The Land: Mountains—Tablelands—Plains—Deserts......... 71
The Ocean: Density—Weight—Colour—Composition—Depth —Ocean Deposits—Animal Life—Sounding—The Pressure, how Found—Temperature—Oceanic Circulation—Waves —Currents—Inland Seas 86
Sea's Action upon the Crust of the Earth 102
Waters of the Land—Springs—Rivers—Transporting Power 103
Table of River Systems—Lakes, Origin of—Use of 109

THE ATMOSPHERE.—Composition—Pressure—Height of—Barometer—Relation with Light 115
Thermometer — Temperature—Winds—Anemometer—Anemoscope—Trade Winds, &c. — Storms—Cyclones—Anticyclones 124

VAPOUR, EVAPORATION, AND CONDENSATION.—Dew—Hygrometer — Clouds — Rain —Rainfall — Raingauge — Snow—Ice—Glaciers.......................... 132
Denudation 141
Phenomena of the Arctic and Antarctic Regions 144

CLIMATE.—Causes Affecting it—Representation of.. 146

METEOROLOGY.—Weather 151

LIFE AND ITS DISTRIBUTION—ANIMALS AND PLANTS.
Horizontal and Vertical Distribution of Vegetation......... 153
Distribution of Animals—Representative of Marine Life... 157
DISTRIBUTION OF MAN 161

PART II.

LIGHT.--Theories concerning the Nature of—Ether—Propagation and Velocity of Light—*Aberration,* Constant of—Reflection —Refraction—Limiting Angle—Lenses--Achromatic Lenses —The Telescope—Solar Microscope............................ 164

PLANETARY MOTION.—Form and Motion of the Planets—Elliptic Orbits—Kepler's Laws—Zodiac—Nodes—Elements of the Orbit.. 170

FORM AND SIZE OF THE EARTH.—Geodetical Surveys—Density of the Earth—Methods of Measurement—Map Projections... 174

PAGE.

MOTIONS OF THE EARTH.—Diurnal Motion—Annual Motion—Plane of the Ecliptic—Apparent Motion of Sun and Stars—Equation of Time—Day and Night—Seasons—Nutation—Precessional Motion—Revolution of Apsides—Eccentricity of the Earth's Orbit—Effect upon Climate 182

LATITUDE AND LONGITUDE.—Declination and Right Ascension—First Point of Aries—Transit Circle 187

DISTANCES OF HEAVENLY BODIES.—Measurement of Distance of the Moon—Methods of Measuring the SUN'S DISTANCE (1) From Moon's Distance; (2) Mars' Distance; (3) Transit of Venus; (4) Velocity of Light; (5) Jupiter's Moons—Parallax of Chief Planets 191

THE MOON.—Distance of the Moon—Motions—Synodical Period—Libration—Phases of the Moon—Rising and Setting—Harvest Moon—Surface of the Moon—Mountains—Craters—Eclipses—Occultations—The Tides—Tidal Wave 195

PHYSICAL CONSTITUTION OF THE SUN.—Volume and Mass of the Sun—Its Motion through Space—The Photosphere and Chromosphere--Successive Strata of Atmosphere--Heat and Light from the Sun—Surface of the Sun—Sun Spots—Sun's Rotation on its Axis—Influence of the Sun on the Earth—11-Year Cycle of Sun Spots—Magnetic Storms—Cause of the Periodicity of Solar Disturbances 201

THE SOLAR SYSTEM.—Bode's Law—Table of the Solar System—Mercury—Venus—Mars—Asteroids—Jupiter—Saturn—Saturn's Rings—Uranus—Neptune—Satellites. Comets, and Meteors—Shooting Nebulæ—Stars—Radiant Points ... 207

FIXED STARS.—Number—Distance—Variable Stars—Colour of the Stars—Classification of Stars—Magnitude—Explanation of Phenomena Exhibited by Variable Stars—Nebulæ and Star Clusters—Nebular Hypothesis.. 220

THE PRINCIPLES OF THE SPECTRUM ANALYSIS.—Fraunhofer Lines—Solar Spectrum—Constitution of the Sun—Reversing Layer—Sun's Condition—Chromosphere—Sun Spots—Velocity with which Vapours move—Spectra of Stars—Measuring Rates of Motion of Stars—Nebulæ—Summary of Spectroscopic Facts 227

TERRESTRIAL MAGNETISM.—Aurora Borealis—Magnetic Instruments 238

NEBULAR HYPOTHESIS............. 241

EXAMINATION PAPERS.. 245

Index 258

THE ELEMENTS OF PHYSIOGRAPHY.

PART I.

PHYSICAL GEOGRAPHY relates to the great natural features and arrangements of the globe regarding the land, water, atmosphere, and animal and vegetable life; but Physiography extends over a much greater scope, taking us into Chemistry and Geology to inquire into the nature of the materials of which the earth is composed, the origin of the different rocks, and their relative ages and history; into Astronomy, regarding the earth as a member of the solar system; and into Physics, inquiring into the laws of gravitation, the electricity and magnetism of the earth, and into the effects of these forces. Hence we may conveniently treat of the subject under five chief heads, namely, Physics, Chemical Elements, Geology, Physical Geography, and Astronomy.

PHYSICS;

OR, NATURE'S FORCES AND THEIR MEASUREMENTS.

Before considering the different forces which affect our planet, it is necessary that the student should possess some elementary notions of the *action of force;* and before we can *measure* its effects it is necessary that we should have some standard to compare with. Hence certain units of measurement are adopted, namely, units of time, units of space, and units of mass.

1. Unit of Time.—The mean solar day is the unit by which time is measured for ordinary purposes, it being the *mean duration of a revolution of the earth upon its axis,* or the interval of time that elapses between two passages of the sun across the meridian. This is divided into twenty-four parts, called hours; these hours into sixty parts, called minutes; and these again into sixtieths, called seconds. The second is usually employed in mechanics as the unit of time.

2. **Unit of Space.**—The English unit of length is the Imperial yard, which is defined to be the distance between two marks on a metallic bar, kept in the House of Commons, when its temperature is 60° F. That this standard may not be lost very accurate comparison has been made with the *pendulum*, from which it has been found that a pendulum in the latitude of London will vibrate or swing from the highest point on one side to the highest point on the other side in one second of time, and will always, under the same circumstances, have a constant length of 39·1393 inches. There are also certain copies of the standard yard kept in various places.

The yard is divided into thirds, called feet; and the foot into twelfths, called inches. The statute mile is 1,760 times this unit, and the nautical, or sea mile, nearly 2,029—it being the length of one mean minute of longitude at the equator. Hence it is more suited for geographical and nautical measurements.

3. **Unit of Mass.**—The English unit of mass is the Imperial pound, which is equal to a certain piece of platinum kept in the House of Commons, certified copies of which are kept in various places. It has also been found equal to 7,000 grains, one grain being $\frac{1}{252\cdot458}$ of a cubic inch of distilled water at a temperature of 62° F.*

4. In the **Metric System of Length** the base is the *metre*, which is defined to be the ten-millionth part of a quadrant of the earth's meridian from the pole to the equator, and equal to 39·3708 of our standard inches. This metre is divided into tenths called decimetres; one-tenth of a decimetre is called a centimetre; and a tenth of a centimetre a millimetre. The centimetre, or the hundredth part of a metre, is usually called the unit of length; and the kilometre, or one thousand metres, is used for the measuring of longer distances. The unit of mass in this system is the *gramme*, which is defined to be equal to the mass of one cubic centimetre of distilled water at 4° C.

5. **Measurement of Velocity.**—Velocity is the rate at which a body moves or changes its position, and is always proportional to the force by which the body is put in motion—motion being the changing of position of any body. There are two kinds of velocity—uniform and variable—it being uniform when equal spaces are passed over in equal times, and variable when passed over in unequal times. Uniform velocity is measured by the space passed over in a unit of time, as one foot in one minute, or one mile in one hour, and so on, the greater the space and the shorter the time the greater is the velocity.

---

* This is the pound Avoirdupois, the pound Troy containing 5,760 grains.

If the space is given, and the time of the body passing over it, the velocity will be equal to the space divided by the time. Thus, if a body move 15 miles in 3 hours, its velocity is 15÷3=5 miles an hour. The time of a body in motion may be found by dividing the space by the velocity, and the space by multiplying the velocity by the time.

Variable velocity *is measured at any instant by the space which would be passed over in a unit of time, if the body moved during that unit of time at the same rate that it had at the instant in question.*

Velocity is called accelerated when it moves over a greater number of units of length in each succeeding unit of time, and retarded when it moves over a lesser number of units of length in each succeeding unit of time. If the velocity is accelerated uniformly the space described in the given time is equal to half the space described in the first unit of time multiplied by the square of the time.

6. **Force.**—*Force is that which causes motion, changes the direction of that motion, or causes it to cease.* It is sometimes divided into two kinds, namely, external and internal, external acting upon matter at sensible distances, and internal, or molecular forces, acting only upon particles of matter at insensible distances—that is, which are too small to be measured. These again may be subdivided into attraction, repulsion, polar or magnetic forces, elasticity, animal and mechanical forces, &c.

7. **Composition and Resolution of Forces.**—It is usual in mechanics to represent forces by lines and numbers, the forces bearing the same proportion to each other as the lines or numbers do; and if the lines are taken in the direction of the force, as well, they represent the *magnitude and direction* of the force.

Any body that is acted upon by two forces would move as if urged by a single force whose magnitude and direction would be represented by the diagonal of a parallelogram, the sides of which represent the magnitude and direction of the two forces. For example, suppose the body A in the annexed figure is acted upon by a force whose magnitude and direction are represented by A C, and at the same time by another force whose magnitude and direction are represented by A B, the single force represented in magnitude and direction by A D will produce exactly the same result if the other two forces were taken away; or if A D was reversed it would just balance or keep in equilibrium the two forces A C and A B.*

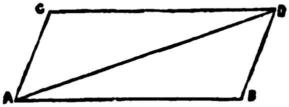

Fig. 1.

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* To complete the parallelogram draw C D equal and parallel to A B and B D equal and parallel to A C.

This finding a single force which will produce the same effect as two others is called the composition of forces, the two forces being called the *components* and the single force the *resultant.* The inverse process—namely, of finding two or more forces that shall produce the same effect as one single force—is called the resolution of forces.

8. Experimental Proof of the Parallelogram of Forces.

Let C and B be two small pulleys, so constructed that the friction shall be as small as possible, and fastened to a vertical board; also, let P, Q, R, be three forces, or weights, fastened to the ends of three cords of fine silk, the other ends being carefully knotted at the point A; the weights will become in equilibrium, the point A being kept at rest by the three forces P, Q, R acting in the direction of the three cords. Along A C take A c equal to as many units of length as there are units of weight in P, and A a along A B equal to as many units of length as there are units of weight in Q. Complete the parallelogram A c b a, producing the diagonal A b, which will *be in the same straight line as* A R, *and containing the same number of units of length as* R *contains units of weight*, thereby proving the truth of the parallelogram of forces.

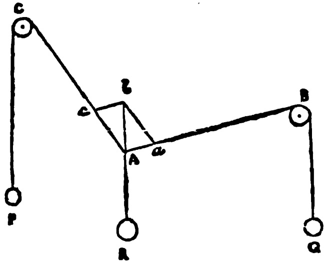

Fig. 2.

Arithmetically—Let P = 16lb. and Q = 12lb., and acting at an angle of 90°, then $Ac = 16$ and $Aa = 12$ units of length.

Hence the diagonal may be found thus, by Euclid I., XLVII. :—

$$Ab^2 = Ac^2 + Aa^2 = 16^2 + 12^2 = 256 + 144 = 400.$$

$$\therefore Ab = \sqrt{400} = 20 = \text{resultant of P and Q.}$$

If the angles are any other than 90° the resultant may be easily found by the use of the scale of proportionate parts. Thus, supposing the two forces are 4lb. and 3lb. respectively, and the angle 60° :—

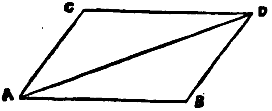

Fig. 3.

Take any scale, say 1lb. to an inch, remembering, the larger the scale the more correct the answer. From the point A draw the two lines A C and A B, inclined to each other at an angle of 60° (which can easily be done by the aid of the protractor), mark off A C = 3 inches, and A B = 4, complete the parallelogram A B D C. Draw the diagonal A D, which will be found to measure a very little trifle over 6 inches; therefore the magnitude of the resultant is 6lb. in the direction A D, the angle made by this with the line A B being $25\frac{1}{2}°$.*

In a similar manner we can find the components when their resultant and direction—that is, the angles they make—are given. Thus, giving the resultant to be 6lb., and the direction which it makes respectively 30° and 45° :—

From the point A draw the two lines A C and A B any length, inclined to each other at an angle of 45° + 30° = 75° ; then produce A D, equal to 6 units of length, making an angle with A B of 30° ; draw C D and B D parallel to A B and A C. It is evident they will cut off the necessary lengths of the components.

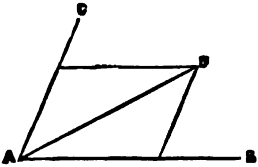

Fig. 4.

9. Polygon of Forces.—When a body is acted upon by more than two forces at the same time, we must take any two of them alone and find their resultant, and then take the resultant as a new force in conjunction with the third, find their resultant, and so on, whatever be the number of forces.

10. The Resultant of any two forces is also always described by the third side of a triangle, whose other two sides represent the forces in magnitude and direction. For instance, in Fig. 3, if we have given AC and CD, AD can be found without drawing the other two sides of the parallelogram. This is called the *triangle of forces*. By this method the resultant of a number of forces may in many cases be obtained more easily. When three forces act in the direction of the three sides of a triangle they will remain at rest.

11. Velocities.—The method of composition and resolution of forces is also applicable to velocities. Thus, supposing a ball moving along a smooth horizontal floor, at a rate of four feet per second, is struck at a certain point in a direction inclined at 60° to its original path, a velocity of 3 feet per second being communicated to it, the resulting velocity is found to be 6 feet per second in the direction A D (Fig. 3, page 10), by exactly the same construction.

---

* By Trigonometry the solution is thus: Taking P and Q to represent the forces, and R their resultant—that is, A C = P, A B = Q = C D, and A D = R, A C D = 180° − C A B = 120°.

$\therefore R^2 = P^2 + Q^2 - 2PQ \cos. 120° = P^2 + Q^2 + PQ$, since $\cos. 120° = -\frac{1}{2}$.

Hence $R = \sqrt{9 + 16 + 12 = 37} = 6{\cdot}032$lb. and the direction of $R = \frac{CD}{AD}$

$\sin. 120° = \frac{4}{\sqrt{37}} \sin. 120° = \frac{4\sqrt{3}}{2\sqrt{37}} = \frac{2 \times \sqrt{111}}{37} = {\cdot}5695 = 34° 43' =$ angle CAD,

or angle $BAD = \frac{3\sqrt{3}}{2 \times \sqrt{37}} = \frac{31{\cdot}60695}{74} = {\cdot}4271 = 25° 17'$

There are the simple cases of forces and velocities requiring notice. If a body is influenced by two forces of 80lb. and 60lb., acting in opposite directions, its resultant force is evidently equal to 20lb. in the direction of the greater force; but if both forces act in the same direction, its resultant is the sum of the forces, or 140lb. In a similar manner resulting velocities are found. For instance, if a vessel is steaming along with a velocity of 12 miles per hour against the tide, which is moving at the rate of four miles per hour, the resulting velocity of the vessel is $12-4=8$ miles per hour; but if steaming with the tide its resultant would be $12+4=16$ miles per hour.

12. **Matter** is the name that has been applied to the earth, with the different substances upon it. It consists of minute particles, or *molecules*, which is the term now used to express the smallest portion of any substance that can exist in a separate state, but still containing groups of atoms, which cannot exist in a separate state, being indivisible.

All matter is continually in motion, either as a whole or among its particles, being acted on by certain forces, each of which has its own special properties. Thus, for instance, a stone, or other mass, unsupported falls to the ground, and would, if there was no resistance, fall to the centre of the earth. Or again, notice how rivers run down hill. There must be a force to cause the water to run at all, and this force is the attraction of *gravitation*.

There are generally three different states of matter recognised—solid, liquid, and gaseous. The force of cohesion being greatest in *solids*, less in liquids, and least in gases. (See "Cohesion," 19.)

A body is said to be *dense* when the *pores*, or spaces between the atoms, are few, so that a large number of particles unite in a small mass; and *porous* when there are many pores, as sponge, &c.

13. **Compressibility.**—Compressibility is the quality of being capable of being forced into a smaller space or compass. All solids, liquids, and gases are compressible; though solids and liquids are very little so in comparison with gases, except in very few cases. The compression of water at 50° F. has been shown by Canton, in his experiments, to be about 46 millionths of its volume, when the atmosphere is in its ordinary state (29½ inches of mercury), alcohol being 66 millionths, sea water 40, and mercury 3.

14. **Gravitation.**—Gravitation is *the tendency of all matter in the universe towards other matter;* or, in other words, any two pieces

of matter have a tendency to approach each other, though in small bodies, or those of only moderate size, it is too feeble to be observed under ordinary circumstances, but in other cases it is presented strongly to us. For instance, notice how a large ship will attract boats, or a teaspoon in a cup of tea the bubbles on the top, &c.

The weight or heaviness of bodies is due to gravitation, called terrestrial, or apparent gravity—weight being the name we give to the effect of gravitation or the measure of the attraction. Newton is said to have been the first who recognised the existence of gravity, and that by the falling of an apple. This same force is exerted on all the planets. For instance, the moon is kept in its orbit revolving round the earth by the attraction of gravitation of the earth; the earth in its orbit round the sun by the attraction of that luminary; the attraction being in all cases *inversely as the squares of the distance of the body from its centre of gravitation.* Hence the force of attraction on bodies at the moon will be $60^2 = 3{,}600$ times less than on the surface of the earth, its distance being 60 times the earth's radius. In a similar manner any matter weighed at either of the poles would be heavier than at the equator, owing to the earth not being a perfect sphere—the equatorial diameter being 7,925 miles and the polar being 7,899 miles. This fact increases the weight at the poles by $\frac{1}{590}$ over its weight at the equator. There is still another cause of the diminution of gravity at the equator, and that is the effect of centrifugal or, as it is sometimes called, centreward force in diminishing attraction, it being greatest at that place, and decreases as we get nearer the poles. As bodies at the equator in their daily motion move more rapidly than near the poles, owing to their radii being greater, a body taken from the poles to the equator loses through this force $\frac{1}{289}$ of its weight. Hence the total loss is about $\frac{1}{194}$; that is, a body of 194lb at the poles weighs 193lb at the equator, $\frac{1}{590}$ of its weight, or 5¼oz., being lost in consequence of its greater distance from the centre of the earth, and $\frac{1}{289}$, or 10¾oz., in consequence of the centrifugal force acting there.

15. The Intensity of the Attraction of Gravitation, or the **Attractive Energy,** not only varies with the distance of the bodies from each other but also with the mass of each body. Hence it is that the sun, the centre of the whole universe, is capable of attracting the most remote planets, though their distances are hundreds of millions of miles from that body, its mass being greater than all the other planets taken together. Hence we have the following law: The force of gravitation between two bodies *is proportional to the product of their masses, and is inversely proportional to the square of the distance between them.*

16. The Law of Terrestrial Gravity is as follows: *The* *force of gravity is greatest at the earth's surface, and decreases upwards as the square of the distance from the centre increases,* and downwards *simply as the distance from the centre decreases,* as, supposing a ball that weighed a pound on the surface of the earth to be taken down to the depth of half the radius of the earth, it is evident there would be the downward force from the earth below it and the upward force from the portion above it. Hence it would be influenced only by the difference between these opposite forces ; and as the downward attraction is twice as great as the upward, it will evidently exceed the upward force by half its original attraction, the other half being balanced by the upward force ; that is, the ball would only weigh one half pound, and if taken to the centre of the earth it would have no weight at all, as the upward and downward forces will evidently balance each other.

From what has been said on gravitational attraction, it would appear that all bodies are drawn towards the earth. Then what causes balloons, smoke, steam, &c., to rise? It is the same force, namely, gravity. When a body is lighter than the air it will rise, as the air, being more strongly attracted, will get beneath it, and, displacing it, cause it to rise. In a similar manner cork, wood, &c., will not sink in water, owing to the same force.

17. All **bodies falling** are acted upon by this force, though those of different material do not always fall through the same number of units of space as each other, or bodies of the same material but different in shape ; yet, were they let fall in a glass receiver with the air pumped out, their times and spaces would be exactly equal, showing that the difference in velocity is caused by the resistance of the air to the falling bodies, varying with their forms and dimensions.

When a body falls the earth attracts it, so that it falls a certain number of feet in the first second of time, the body being then in motion with a velocity of say one unit. The earth still attracts it, and during the second second it communicates to it an additional unit ; so that in every successive second of time the attraction adds to its velocity in a similar proportion. *Hence the spaces passed over in each successive second are as the odd numbers, 1, 3, 5, 7, &c.*

A body left free to move, and acted on directly by the force of gravitation, all resistances being excluded, will, in the latitude of Greenwich, fall through 16·0954 feet in a second, thereby acquiring by this motion a velocity of 32·1908 feet per second. This velocity is called the *force of gravity*, or *acceleration due to gravity*, and is represented by g. The space travelled over by a falling body in one second is 16 feet 1 inch very nearly ; and the space described in

t seconds $= \frac{1}{2} gt^2$. If we know the time required for the fall of any body through a given space, the velocity with which it moves can easily be found, or *vice versa*.

FORMULÆ.—Let v represent the velocity, t the time of descent, s the space described in the time t, and g as above. Then we have :—

$$s = \frac{1}{2} gt^2 = \frac{1}{2} \frac{v^2}{g} = \frac{1}{2} vt \,; \quad v = gt = \frac{2s}{t} = \sqrt{2gs}; \text{ and } t = \frac{v}{g} = \frac{2s}{v} = \sqrt{\frac{2s}{g}}$$

If the body is projected upwards with a velocity v, then $s = vt - \frac{1}{2} gt^2$; and if downwards, $s = vt + \frac{1}{2} gt^2$.

18. Cohesion.—The attraction of gravitation causes a body when unsupported to fall to the ground; but the attraction of cohesion causes the particles to hold together and unite in masses. When the cohesion exceeds the other forces we have a solid; when the forces are equal we have liquid or fluid; and when heat predominates we have gas or vapour. For instance, take a piece of ice. Its particles are held together by cohesion; but take it near a fire and it will soon melt; the cohesive attraction being overcome by the repulsive power of the heat, its particles or molecules are driven asunder, and the ice becomes a liquid; and now, by applying more heat, it is soon converted into steam, which on entering the cold air becomes a watery vapour.

It is gravitation which brings the particles of matter close enough together for the attraction of cohesion to be exerted upon them, as in the case of sandstone and other rocks. When gravitation has finished its work—bringing the loose grains of sand together—cohesion commences, and firmly unites these particles into a compact mass of sandstone.

Heat and cohesion constantly act in opposition to each other. Hence, the more a body is heated the more its particles will be separated. The two may be noticed even in the effect that they produce upon our bodies. For instance, on a warm day our flesh, especially the hands and feet, swells from the effects of the heat, but on cold days contracts, owing to the cold (or absence of heat) causing the particles to cohere more closely together.

It is the attraction of cohesion that causes the small watery particles which compose mist or vapour to unite together in the form of drops of water, rain being thus produced.

In the manufacture of shot we have a good illustration of the parts played by gravitation and cohesion. The lead for the shot is melted at the top of a high place or tower, then a little arsenic is added to give it the exact fluidity. Afterwards it is poured through a kind of sieve, through which it passes by the effect of gravity—namely, its weight—and falls to the ground. In its descent it assumes the form of a sphere through the force of cohesion acting upon it.

19. Molecules and Atoms.—By the term *Molecule*, which is used above as synonymous with particle, we mean the smallest quantity or group of atoms of any substance, whether simple or compound, that can exist in a free state, and is generally composed of two or more atoms, an atom being the smallest quantity of an element which can exist in combination. Thus, for example, the smallest quantity of water which can exist in the free state consists of three atoms, namely, two of hydrogen and one of oxygen, and this is termed a *molecule* of water. Similarly the smallest particle of chalk we can conceive consists of five atoms, namely, one of calcium, one of carbon, and three of oxygen; quartz of three atoms, namely, one of silicon, and two of oxygen. The force of cohesion keeps together the molecules of a compound, or the atoms of the same element, but it is the force of chemical affinity which causes the atoms of different elements to unite, forming a compound substance.

20. Chemical Affinity is that property *by which bodies combine and form new compounds and the power which causes them to continue in combination*. It differs from the attraction of gravity in not acting on masses, and only at insensible distances requiring bodies to be in actual contact. In this last property it resembles cohesion, or cohesive affinity, but differs from it by occurring only between the particles of dissimilar bodies. For instance, the particles in a mass of copper or sulphur are held together by cohesion, but if a particle of the copper comes in contact with a particle of sulphur they unite by the power of chemical affinity—the two particles being different—and form sulphuret of copper.

In chemical compounds the proportion of the two substances is always definite. Thus when oxygen combines with hydrogen to form water, there are always eight units of the former to one unit of the latter, the molecules being united by chemical affinity, but held together by cohesion. The simplest cases of chemical affinity are those in which two bodies unite into a *binary compound*, being the result of *single affinity*, which power may be also exerted either between two elementary or two compound bodies. The force with which bodies chemically unite arises from mutual and equal affinity. Chemical combination produces some remarkable effects, often changing the form, colour, taste, density, and qualities—harmless elements producing strong poisons, and strong poisons harmless compounds.

Among the many agents that influence this affinity the chief are heat, light, electricity, proportion, &c. For instance, potash and sand unite under a red heat and form glass; carbonic acid and lime are separated from marble or limestone by a red heat, &c. Light is also produced by chemical affinity. The majority of substances that give light are composed of hydro-carbon. The oxygen in the air first combines with the hydrogen, it having the greatest affinity for it. The carbon is then set free, and we have an intense light as the carbon passes from the hydrogen into the oxygen during the greatest evolution of heat caused by chemical combination.

In order that chemical affinity may be thoroughly understood from the other forces of attraction we will give another example. If two particles of iron be brought in close contact they adhere close together by the force of cohesion, producing a larger mass, but still possessing properties in all respects identical with those of the particles of which it is composed. In a similar manner particles of sulphur may be made to cohere and form a larger mass of sulphur. But if the iron and sulphur be brought into contact the effect is different, as the mass so obtained is entirely distinct in its properties from either the iron or sulphur, being perfectly homogeneous, showing no traces of either of its constituents, and cannot be again separated into its elements by merely mechanical processes. This is an example of chemical affinity or attraction. It is requisite that all these characters be taken into account to distinguish this affinity or attraction from cohesive attraction, because cohesion does take place between dissimilar particles, as when copper is plated with silver by means of powerful pressure; but here the mass is not homogeneous, and the silver and copper may be at once distinguished.

21. Heat.—The term heat is usually employed to express the sensation of warmth. Until recently heat was supposed to be due to a form of matter—a fluid called caloric, but according to the present idea, it is regarded as due to motion—motion of the molecules of bodies. Heat, like electricity and other allied forces, is a result of molecular vibrations. This conversion of motion into heat is explained by saying that the motion of the mass is converted into a motion of the particles of which the mass is composed. In a similar manner the heat generated by chemical action is explained by Professor Tyndall. He says: "There is first of all the attraction between the atoms; there is, secondly, space between them. Across the space the attraction urges them. They collide, they recoil, they oscillate. There is here a change in the form of the motion, but there is no real loss." *

Bodies are continually interchanging their heat, either by *conduction*, *convection*, or *radiation*. Thus if two bodies of unequal temperature are in contact, they will give off some of their heat to each other, though the hotter of the two will give off more rapidly, so that finally they will each have the same temperature. This is called *conduction* of heat, and goes on incessantly between all bodies in contact. Again, heat is communicated from hot to cold bodies by *radiation*, as, for instance from the sun to the earth. Some bodies radiate heat in greater quantities than others, thus dull surfaces are generally good radiators, and polished surfaces usually bad radiators.

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* "Fragments of Science."

Nearly all bodies expand when heated, though water and bismuth do not follow the general rule. (See 45.) The ratio which the increment of volume, given to any body by an increase of 1° in temperature, bears to the volume of the body at freezing-point is called THE COEFFICIENT OF EXPANSION. Thus, if a volume of gas, air for instance, be heated from 0°C. to 1°C., its volume will be increased $\frac{1}{273}$, which is the coefficient of expansion; hence, if a measure of gas be heated from 0° to 273°C. its volume will be doubled. On the F. scale, the coefficient of expansion is $\frac{1}{491}$. Not only does the volume of a gas change when the temperature changes, but also when the pressure upon it changes. According to Boyle and Marriotte's law, the volumes will be inversely as the pressures—the temperature being the same.

22. Energy.—All matter in motion possesses energy, or the power to do work. It is measured by the work it can perform. This energy cannot be destroyed, even by performing work, being only changed in form. A body may possess energy in one of two forms, namely, as *kinetic* energy or *potential* energy.

Kinetic energy is that which is due to motion, and *potential* energy that which is due to what may be called a position of advantage, or, in other words, of an arrangement capable of yielding kinetic or actual energy, when there is nothing to stop it from so doing.

Thus a moving mass—a bullet or cannon ball, for example—can do work in virtue of its motion; a running stream by its motion works the mill, &c. Energy belonging to molecular motion, electricity in motion, to heat and light, and actual chemical action, are included under the name of kinetic energy; and energy due to absorbed heat, to electrical separation due to chemical separation, or due to being raised up to a certain position so that it is capable of doing work in falling, &c., are included under the name of potential energy. To make plain we will give a few examples for illustration: A stone on being thrown vertically upwards has, on leaving the hand, sufficient power in store to raise it, though opposed to gravity, a certain height. Owing to the effect of gravity its velocity gradually becomes less and less, until its motion upwards ceases, its kinetic energy being now spent.* It now possesses the other kind of energy, viz., potential, owing to its changed position, thereby falling to the ground, and acquiring exactly the same energy as it had in starting; but supposing the stone had lodged on some high building just as its upward motion ceased, it still would have had the same energy, in virtue of its position, but prevented from falling by the building.

23. Heat produces Energy.—When the energy lies dormant in a body it is potential, but this can easily be turned into kinetic by applying heat, electricity, magnetism, &c. For instance, take the water in a boiler, apply heat, and we soon have visible kinetic energy, viz., steam.

Heat expands most substances, and in expanding or contracting they produce kinetic energy. For example, in laying rails on railroads, space is left between each joint for expansion; if not, this force would tear them up out of the ground. Contraction produces equally as strong a force. It is taken advantage of by wheelwrights, coopers, &c. Thus the hoop or tire of a wheel is put on hot, then suddenly cooled, whereon it contracts with great force, binding the wheel and spokes firmly together.

These very forces, looked into, explain such common occurrences as a cold glass vessel breaking when hot water is poured in, or a hot one when cold water is poured in, &c.

To the heated state of the interior of the earth may be attributed volcanoes and earthquakes.

Also, when a body is heated it exhibits energy in diminishing and increasing the powers of electricity and magnetism. For instance, in solids a few degrees of heat will diminish the conductivity of electricity to a great extent, but in liquids, on the other hand, increase of temperature increases the conductivity. Again, an iron bar that has been magnetised suddenly loses the whole of its magnetism at a particular temperature.

24. Electricity, like heat, lies dormant and concealed in matter, giving no indications of its presence when in a latent state; but when liberated is capable of producing the most sudden and destructive results. It may be called into action by friction, chemical action, heat, or magnetic influence. Its simplest form of *energy* may be seen in attraction and repulsion. Bodies charged with opposite kinds of electricity attract each other, and with similar kinds repel each other. A perfectly dry and clean piece of sealing-wax, amber, or smooth glass, sharply rubbed with a dry woollen cloth, will, if applied at that moment, attract small pieces of paper, cork, &c., causing them to adhere for some time—the attracting body being now said to be electrified or excited. They have also the power of communicating their electrification to other bodies; and, again, a body electrified by either of them can electrify a third.

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* Height it will rise $=\frac{v^2}{2g}$ where v = velocity in feet per second, and g = gravity = 32·2; and this, multiplied by the mass = measurement of energy.

There are various ways in which light may be produced from electricity. For instance, the sparks due to the discharge of electrostatic accumulations from the clouds give an intense light—the most magnificent example being lightning.

The greatest known heat with which we are acquainted is produced by the agency of the electric or galvanic current, as all known substances can be melted or volatilised by it.

25. Positive and Negative.—As there appears a difference between the kind of electricity excited by rubbing a piece of glass and that excited by rubbing a piece of wax or resin, Du Fay inferred from this that there are two kinds of electricity—the one vitreous, because especially developed on glass, and the other resinous, because first noticed on resinous substances. He supposed these to exist in equal quantities in all neutral bodies, and that when two bodies are rubbed one on the other they are separated. One of the bodies becomes overcharged with one of the fluids, and the other with the other fluid—it depending on the nature of the bodies which shall receive the excess of the vitreous and which shall receive the excess of the resinous.

The theory that seems most generally admitted now is that of Franklin. He is of opinion that there is but one electric fluid, which possesses an attraction for various substances in various degrees, and that every body in its natural condition is associated with a certain quantity of this fluid. When two bodies are rubbed together friction causes some of the fluid to leave one body and pass to another, whereupon one becomes overcharged or *positively* charged, and the other undercharged or *negatively* charged. Hence the terms positive and negative.

26. Electrical Disturbances.—Telegraph lines are constantly troubled by electrical disturbances, called *earth currents.* They are frequently so powerful as to render the use of the instrument impossible for some time. These disturbances are found to be very closely connected in some way with the perturbations of terrestial magnetism called magnetic storms, which are so closely connected with the aurora borealis and sun spots.

27. Atmospheric Electricity.—The atmospheric medium by which we are surrounded contains not only combined electricity, the same as every form of matter, but also a large quantity of free and uncombined electricity, sometimes being positive and sometimes negative, but generally the opposite kind to that of the earth.

Various kinds of apparatus have been contrived for the examination of the electric state of the atmosphere, such as poles elevated about thirty feet in the air, and being provided with a metallic point at their upper ends, and insulated at their lower ends.

By the aid of these instruments it has been found that, in clear weather, signs of free positive electricity are always present in the atmosphere, it being weak before sunrise, but gradually gets stronger as the sun passes the horizon, and soon afterwards gains its greatest strength; it then rapidly diminishes, and regains its *minimum* state some hours before sunset, after which it again increases, gaining its second *maximum* state, then decreases until the following morning.* It has also been noticed that the electricity of the atmosphere increases from July to January, then decreases, being more intense in the cold weather.

28. Accumulation of Electricity in the Clouds.—The chief sources from which the clouds appear to obtain their electricity are *evaporation* from the earth's surface, the chemical changes which take place on the earth's surface, together with the expansion, condensation, and variation of temperature of the atmosphere and its moisture.

29. Lightning and Thunderstorms.—When a cloud *overcharged* with the electric fluid approaches another which is *undercharged* the fluid rushes from the former into the latter. This discharge produces the vivid flash known as lightning, accompanied by the sound of thunder, which is similar to the report of a gun when discharged or fired. When successive discharges of the accumulated electricity take place it causes great disturbance in the air, thereby causing *thunderstorms.* The air being suddenly rarefied and dispersed, in the course of the lightning, rushes together again after the discharge has passed. In this way the air is perhaps disturbed for miles at the same time.

The most dreaded of lightning is what is sometimes called the *returning stroke,* as the earth containing positive electricity, or being overcharged, returns its overplus to the clouds. The flash of lightning always proceeds from a positive body—that is, one which is overcharged with electric fluid.

From observations made in Saxony, and Kremsmunster, in Bavaria, the conclusion has been arrived at that there is a periodicity in thunderstorms as well as in other natural phenomena. Thus, according to Von Bezold, in all years when the temperature is high and the sun's surface relatively free from spots, thunderstorms are abundant. It has also been observed that the maxima of the sun's spots coincide with the greatest intensity of auroral displays. It follows that both groups of phenomena, thunderstorms and auroras, to a certain extent, supplement each other, so that years of frequent storms correspond to those of auroras, and *vice versa.* (See 36.)

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* Becquerel Traié, t. iv., p. 84.

Thunderstorms are very beneficial. They purify the air by producing *nitric acid* and *ozone,* which dispel noxious vapours, and by agitating the air stir up fresh currents of air or breezes, thereby causing it to be more healthy and pure.

30. Thunder.—Several explanations have been put forth as to the cause of the noise that we call thunder. One is, that it owes its origin to a sudden displacement of air caused by the discharge of electricity which produces the lightning; another is that the passage of the electric current causes or creates a vacuum, which the air rushes in to fill up, thereby producing the sound.

31. Magnetism is the name given to the peculiar property possessed by certain bodies, especially iron and its compounds, whereby, under certain conditions, they mutually attract and repel each other.

There appear to be two species of magnetic power—the northern and the southern—which are perfectly similar in their mode of action, but directly opposite in their effects. For instance, take two magnets, and it will be found that the two north poles (see 33) always repel each other, and the two south ones likewise; but the north pole of one magnet invariably attracts the south pole of the other, or the south pole the north. Hence between *like* powers there is *repulsion,* and between *unlike, attraction.*

If a bar of malleable iron is placed near the poles of a magnet it will become immediately magnetic, either with or without contact. This is called *induction.* Each pole of the magnet induces the opposite kind of *polarity* in that end of the iron which is nearest to it. This bar of iron has now acquired the power of inducing a similar state of magnetism on other iron near it, and also reacts upon the magnet from which it first derived its power, increasing the intensity of its magnetism.

It has been found that the attraction and repulsion existing between two magnetic particles are always *inversely as the square of the distance,* thereby agreeing with the law observed in electricity, the force of gravity, and every other known force proceeding from a centre in right lines. Coulomb introduced the theory of two opposite magnetic fluids, viz., a *boreal fluid* and an *austral fluid,* and that the magnetic body consists of small particles. The fluids, in their activity, are separated in each such particle, but never pass out of it. The amount of magnetic action is to be calculated as the accumulation of the magnetic forces of the several particles—that is, as the statical resultant of all those forces. It is necessary to remember, in reference to a magnetic bar, that the terms *boreal*, *southern*, and *positive*, all refer to that pole which would point towards the south, and *austral*, *northern*, and *negative*, to that which would point towards the north.

TERRESTRIAL MAGNETISM AND ELECTRICITY.

32. **The Earth** itself may be regarded as a spherical magnet, whose north pole corresponds to the south pole of an ordinary magnet, and its south pole to the north. The cause of the earth's magnetism may be on account of the crust being largely composed of iron and other magneticable metals; or, perhaps, due to the earth currents moving from east to west around the earth, as the successsive parts of the earth face the sun.

Dr. Faraday was of opinion that the magnetism of the earth is the result of the induction* of the electric currents; or, if a terrestial magnet really exists, its poles are close together near the earth's centre.

33. **Mariner's Compass.**—A magnetic bar, balanced, by being fixed at its centre of gravity on a pivot, will, if free to move, after a few oscillations, assume a constant position, one end pointing to the north, hence called the north pole of the magnet, and the other end to the south, called the south pole. This is the principle of the mariner's compass, which guides the sailor when all other indications of his course fail him.

To account for this property of the magnetic needle the earth is supposed to be or to contain an enormous magnet, the poles of which correspond very nearly to the geographical poles of the earth. According to Sir J. C. Ross the north magnetic pole is situated in lat. 70° N., long. 97° W., and the southern pole in lat. 75° S. long. 184° E.

The magnetic needle does not point exactly north and south. Hence the magnetic meridian does not coincide with the geographical meridian; or, in other words, the north-seeking pole of the magnet does not agree with the geographical north pole. The difference between the two is called the *declination*, or *magnetic variation*. It is measured by taking the angle made by two vertical planes, one passing through the earth's axis and the other through the needle.

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* Induction is the production of *like effects* in *bodies near to one another.*

At London the north-seeking end points about 17° west of north. The magnetic needle, when suspended on an axis at its centre of gravity, does not maintain its horizontal position—its *austral* or northern-pointing end dipping considerably in our hemisphere, and in the southern the opposite pole inclines. This is called the *dip* or *inclination* of the needle, the needle being called a *dipping needle* or *inclination needle*. The inclination in this latitude to the horizon being about 70°, it undergoes periodic variations, though small in comparison to the declination.

Lines passing through places having the same declination are called *isogonal lines*, and lines connecting places where the dip is the same are called *isoclinals*.

Observation has taught us that the magnetic poles change their position gradually during long intervals of time, and that they coincide with the points where the greatest degree of cold is felt or where the mean of the thermometer for the year is lowest on the surface of the earth.

Besides this change there is the daily variation in the magnetic needle, which commences about midnight or shortly afterwards. The north-seeking pole moves to the east. At about seven or a quarter past it is found to be 6′ or 7′ from its mean position. It then returns, passing the mean magnetic meridian about ten o'clock, reaching its greatest deviation—probably 3° from the mean—between one and two in the afternoon. It now starts towards the east, passing the mean at about five or six o'clock, still continuing to move slowly on till ten or eleven, when it moves so slowly as to be insensible for some time.

It is believed that the sun is the principal agent in causing the variations. Professors Christie and Barlow, from experiments and observations, were led to the conclusion that the daily motion was dependent upon the relative position of the sun with respect to the magnetic meridian, and that the proximate cause was to be traced in the altered distribution of temperature.

There are still other variations—namely, monthly and yearly—which may be called solsticial variation, but very little definitely is known respecting them.

34. Magnetic Elements.—In determining the state of the earth's magnetism at any place, and at any time, there are three things to be observed, viz., the *magnetic declination*, the *magnetic inclination*, and the *total force*, or *intensity*. The declination and inclination are explained above. The total force, or intensity, is a number which expresses the force of magnetic attraction at the place and in the direction of the dipping needle. It is properly expressed in absolute units of force. Sometimes the *horizontal* *force* is given instead of the total intensity. The latter is derived from the former, by *multiplying it by the secant of the angle of the dip.*

A unit of magnetism is usually defined as follows: A magnet is said to have a unit of free magnetism when it fulfils the following conditions: Let the magnet be free to turn in a horizontal plane, and at the same time, in the same plane, let there be another magnet, precisely similar and equally magnetised, at right angles to it, and opposite its centre, at a distance of one millimetre from it, then the former magnet has one unit of magnetic force if it tries to turn round with a force equal to that which would be exerted by a force of one milligram acting at right angles to an arm one millimetre in length.

The magnetic elements for 1884 at Greenwich were as follow: Declination, or variation of compass, 18° 10′ W.; inclination, or dip of the needle, 67° 30′; horizontal force, in British units, 3·9; total force (1884), 10·27.

35. Magnetic Storms.—From observations in various parts of the globe the occasional occurrences which have been termed magnetic storms have been noticed. During these storms the magnetic elements—namely, the declination, and the amount of its horizontal and vertical components—are subjected to violent changes, which appear, frequently at the same time, over immense tracts of the earth's surface. For instance, a disturbance which occurred at Toronto, in Canada, was found to agree precisely in time and very nearly in amount with a similar disturbance registered at Greenwich.

From registrations taken at Greenwich and Toronto the occurrence of aurora borealis has been found, in nearly all cases, to be accompanied by magnetic disturbance at both places. It has also been proved that the magnetic storms are in some way or other connected with the spots of the sun. Schwabe, of Dessau, shows that the various epochs of maximum spot frequency are also those of maximum magnetic disturbance of our globe. It is a remarkable fact that when a spot is forming on the sun our magnetic needles are unusually disturbed.

36. Aurora Borealis, or Northern Light.—So called because they appear in the north. They are flashes of light of various colours, sometimes taking the form of a dark segment, or of an arch or crown, sometimes in the form of luminous streamers. They are frequently seen in the North of Europe, and of late years not unfrequently in this country. The cause of them is supposed to be the passage of electricity through the higher regions of the atmosphere, where it is highly rarefied.

It has been calculated that its probable height is usually between seventy and eighty miles. Hence the density of the atmosphere would only be about the one hundred and fiftieth part of that at the earth's surface.

Several other reasons have been put forth at different times to show the cause of these lights, nearly all agreeing that it is within the region of our atmosphere. Heli ascribed it to the reflection of the sun and moon by the clouds of snow and needles of ice which continually float in the polar regions. Bailly ascribed it to magnetism, it being remarkable that magnetic disturbances have generally been noticed at the same time. Franklin attributed it to electricity. Kastner was of opinion that the polar lights are the electricity of the earth rising periodically to the poles.

Similar occurrences have been seen at the south of the Southern Hemisphere, but not so frequently. They are called aurora australis.

If an oval is drawn round the North Pole, passing through Iceland, the North Cape, Gulf of Obi, Northern Siberia, the mouth of the Mackenzie River, the centre of Hudson's Bay, and Nain, it includes the region where the greatest number occur, averaging about forty annually.

CHEMICAL ELEMENTS.

OR THE CRUST OF THE EARTH VIEWED CHEMICALLY.

37. Chemical Action is the name applied to those operations, whatever they may be, by which the weight, form, solidity, taste, smell, colour, and action of substances become changed, forming new bodies, with different properties from the old. For instance, if we take some water and mix with it sulphuric acid, chemical action takes place, and the two cold liquids produce intense heat; if we pour cold water on lime there arises heat from it, by the chemical action; or if we take 56 grains of iron and 32 grains of sulphur, chemical action takes place, the two substances forming *ferrous sulphide* (sulphide of iron), which differs in appearance and properties from both iron and sulphur.

Chemical action assists the formation of rock masses, acting thus: First, the deposit becomes dry and contracts. It is then covered over with fresh layers, and exposed to great pressure, and also to an increased temperature, owing to the greater depths, the water carrying in chemical solutions (which arise from the water passing through the earth and coming into contact with many different minerals and substances) all the time from one layer to the under or lower ones.

Chemical action generally produces a change of temperature or a change of state, and often a change in colour.

38. Compounds.—The laws according to which chemical substances combine and form compounds are very simple. The first and chief is that a compound is perfectly homogeneous, and that its composition is fixed and invariable.

From experiments we learn that if a quantity of hydrogen, for instance, is taken and tried to make combine with bromine or chlorine we must take 79·75 times its weight of bromine, or 35·5 times its weight of chlorine, as they cannot be made to unite in any other proportion. Hence if we see any substance that can be recognised by its external properties as a compound of hydrogen and bromine, we are certain that its constituents are in the proportion of 1 to 79·75; or if the compound is of hydrogen and chlorine, those elements will be in the proportion of 1 to 35·5.

Again, suppose we take potassium and bring it in contact with the latter compound, viz., hydrogen and chlorine, it will at once expel the hydrogen and unite with the chlorine, forming a compound of potassium and chlorine, taking 39·13 parts of potassium to replace the one part of hydrogen. By similar experiments it is found that 23·05 parts of sodium satisfy the affinity of 35·5 parts of chlorine, or 107·94 parts of silver can replace the 39·13 parts of potassium. In this way there could be obtained for each of the elements a number expressing the quantity of it that will satisfy the affinity contained in one part of hydrogen. These numbers, expressing the proportion in which the elements combine, represent also the relative weight of the atoms of which the different kinds of matter are composed. For instance, an atom of chlorine equals 35·5 times the weight of an equal volume of hydrogen, the weight of an atom of chlorine being 35·5, and an atom of hydrogen 1. Hence the term *atomic weight*, the atoms being all the same size, with one or two exceptions, namely, phosphorus and arsenic, whose atoms are supposed to be half the usual size, and mercury, zinc, and cadmium, whose atoms are twice the size. An *atom* is the least part of an elementary body which can enter into or be expelled from a compound.

39. Chemical Elements.—When the different substances found at the surface of the earth are submitted to various methods of treatment, the majority of them can be broken up into several substances of a more simple nature. Thus, a piece of flint can be separated into two substances entirely different from it in appearance and properties, wood and chalk into three, alum into four, and so on; while others, as iron, gold, copper, sulphur, &c., resist all the processes to which they have as yet been subjected, and appear to consist of only one kind of matter. It has been found by submitting all the rocks, minerals, animal and vegetable substances, &c., to appropriate processes, that they contain about sixty-five substances, by the union of which all the different kinds of matter are made. These sixty-five substances are called the chemical elements. The following is a list of them, with their symbols and atomic weights, that is "the proportions in which they combine among themselves." No combinations can take place among the elements except in these proportions, or multiples of them :—

	Names.	Symbols.	Atomic Weight.
a	**Hydrogen**	H	1
a	**Chlorine**	Cl	35·37
a	Bromine	Br	79·75
a	Iodine	I	127
a	Fluorine	F	19
	Potassium	K	39·13
	Sodium	Na	23
	Lithium	L	7
	Caesium	Cs	133
	Rubidium	Rb	85·4
	Silver	Ag	108
	Thallium	Tl	204
	———		
a	**Oxygen**	O	16
	Barium	Ba	137
	Strontium	Sr	87·5
	Calcium	Ca	40
	Indium	In	113
	Magnesium	Mg	24·4
	Zinc	Zn	65
	Cadmium	Cd	112
	Copper	Cu	63·5
	Mercury	Hg	200
	Glucinium	G	9·3
	Didymium	D	96
	Lanthanium	La	92
	Yttrium	Y	61·7
	———		
a	**Boron**	B	11
	Gold	Au	196·7
	———		
a	**Carbon**	C	12
a	**Silicon**	Si	28
	Aluminium	Al	27·5

	Names.	Symbols.	Atomic Weight
	Zirconium	Zr	89·5
	Thorium	Th	116
	Tantalum	Ta	138
	Niobium	Nb	97·5
	Tin	Sn	118
	Titanium	Ti	50·4
	Lead	Pl	207
	Platinum	Pt	197·3
	Palladium	Pd	106·5
a	**Nitrogen**	N	14
a	**Phosphorus**	P	31
	Arsenic	As	75
	Antimony	Sb	122
	Bismuth	Bi	208
	Vanadium	V	52·4
	———		
a	**Sulphur**	S	32
a	Selenium	Se	79·4
	Tellurium	Te	128
	Chromium	Cr	52·5
	Manganese	Mn	55
	Iron (Ferrum)	Fe	56
	Nickel	Ni	58·8
	Cobalt	Co	58·8
	Cerium	Ce	92
	Uranium	U	240
	Tungsten	W	184
	Molybdenum	Mo	92
	Rhodium	Ro	104
	Ruthenium	Ru	104
	Iridium	Ir	197
	Osmium	Os	199
	Gallium	Ga	*
	Lavœsium	La	*

The elements marked *(a)* are non-metallic, the remainder being metallic. The most important of the elements are printed in black type, the general character of the chief of which we here give:—

OXYGEN is a gas which is devoid of colour, taste, or smell. It is transparent and invisible. It possesses the mechanical properties of common air. It is capable of being respired, and a given volume of it will support life longer than an equal bulk of common air. It possesses great power of combination with other elementary bodies, there being scarcely one which is not known to combine either by direct union, or in direct chemical action. The most remarkable property of oxygen gas is the facility and splendour with which bodies when previously ignited burn in it. Substances which do not undergo combustion in the air will readily do so, and with great brilliancy, in oxygen gas. (See also 44.)

CARBON is a non-metallic solid element. The commonest form in which we find this substance is a charcoal—black charcoal. It is also very common in the form of black-lead, of which drawing pencils are made. Other names for this form of carbon are plumbago and graphite. It also occurs in nature as diamond, being very pure carbon crystallised.

Carbon exists in combination with other elements as gases. Thus with oxygen it forms carbonic acid gas (CO_2) in all animal and vegetable substances. The coal we burn contains large quantities of this element together with hydrogen.

SILICON is of a dark brown colour, has no lustre, and is a non-conductor of electricity. It is insoluble in water, and incombustible in air or in oxygen gas. No other element, excepting oxygen, is more commonly found in the earth's crust. It is, however, never found in a free state, but in combination with oxygen, as a dioxide forming silica, of which flint, quartz, and sand are chiefly composed. It is next to oxygen the most widely diffused element in the earth's crust.

CALCIUM is a yellowish white metal, which can be rolled into sheets and hammered leaves, and is intermediate between lead and gold in hardness. Combined with oxygen it enters into the composition of many rocks.

MAGNESIUM is a silver white metal. When strongly heated it burns with great brightness. It decomposes cold water slowly, and acidulated water very quickly. When burnt in air its oxide, *magnesia*, is formed.

SULPHUR, or as it is often called, *brimstone*, is found free in volcanic countries, such as Sicily, Iceland, &c. It has, when thus met with, a crystalline form, known as *octohedron*, with rhombic base. It combines directly with most metals. Is soluble in carbon bisulphide, but not in water or alcohol.

CHLORINE is a gas of a yellowish colour. It never occurs free, naturally, but always in combination with some metal or other. It has a very strong, suffocating odour. Is somewhat soluble in cold water, and combines very readily with metals. The compounds of chlorine are termed chlorides: thus common salt is the chloride of sodium.

SODIUM is a metal which is found naturally in combination chiefly with chlorine, in the form of salt, in sea water, and in this state pervades the earth and air universally. It has a bluish-white colour. Water is decomposed by it. When thrown on hot water, the liberated hydrogen and sodium burn with a yellow flame.

POTASSIUM is a bright silver-white metal. It rapidly oxidises when exposed to air. It readily combines with chlorine, sulphur, and other metalloids. When thrown on water, it bursts out into a violet flame, displacing the hydrogen of the water. Like sodium, it always occurs in nature in combination with other substances, as *felspar, mica, alum, nitre,* and in sea water.

HYDROGEN is a colourless gas. It has no smell, and is the lightest body known. It enters largely into the composition of water, and is also a constituent of most animal and vegetable bodies.

NITROGEN is also, like hydrogen, a colourless gas. It has no smell and does not support life. It exists largely in nature combined with other elements, in animal and vegetable substances.

40. Atomicity.—The elements have also different powers of combining. For instance, one atom of Cl (see table) can only combine with one atom of H, but an atom of O can combine with two, N with three, and C with four atoms of the same element H. Hence an atom of O has the power of replacing, or is *equivalent* to, *two* atoms of Cl, an atom of N to *three*, an atom of C to *four*, of the same element, &c. In a similar manner an atom of nitrogen can be substituted for five, tin for four, iron or cobalt for six, of any monad element—as hydrogen.

Those elements whose atoms are equivalent to one atom of hydrogen are called *monads;* those whose atoms can replace two atoms of hydrogen, *dyads;* those whose atoms can replace three, *triads;* four, *tetrads;* five, *pentads;* and six, *hexads.* In the above table those in the first group are *monads;* second group, *dyads;* third group, *triads;* fourth group, *tetrads;* fifth, *pentads;* and sixth, *hexads.*

The symbols annexed to each element are letters used to denote them without writing their names in full. In most cases the initial letter of the common or of the Latin name is used. This symbol also expresses, by remembering or referring to the atomic weights of the substance, the quantity by weight of the substance entering into combination. For instance, Cl not only denotes an atom of chlorine but an atom consisting of 35·5 parts by weight of that element ; N, an atom, or 14 parts by weight, of nitrogen ; and so on. More than an atom of an element is expressed by a small figure placed below the symbol on the right, as Cl_2, the figure denoting the number of atoms.

41. Binary Compounds are *composed or formed by the union of elements*—namely, *in the proportion of their atomic weights*—as for instance, sodium and chlorine unite and form the compound sodic-chloride, having properties entirely different from either of the elements—there being 23 parts sodium and 35·5 parts chlorine.

The symbols of compounds are formed by the juxtaposition of those elements. Thus, HCl represents one atom of hydrogen combined with one atom of chlorine, forming hydrochloric acid. It also further expresses the fact that the compound hydrochloric acid is formed of 1 part of hydrogen and 35·5 parts of chlorine.

The principal binary compounds are: Water, H_2O ; lime, CaO ; magnesia, MgO ; Soda, Na_2O ; quartz or silica, SiO_2 ; chloride of lime, $CaCl_2$; rock salt, NaCl ; carbonic acid, or carbonic dioxide, CO_2. The proportion of each constituent may be known by remembering or consulting the atomic weights of the elements. Thus, the formula of soda is Na_2O ; hence, remembering Na is 23 and O 16, the proportions by weight are 23 × 2, or 46 of sodium to 16 of oxygen.

Brief Notes on the Binary Compounds.—For Water, see 44 and 45.

LIME—(CaO) or oxide of calcium, is composed of calcium and oxygen. It is a white, opaque, inodorous, acrid, alkaline, and infusible substance. It possesses a great affinity for water, with which it combines, during which action it heats, swells, cracks, becomes powdery, and forms hydrate of lime, or slacked lime.

MAGNESIA (MgO) is formed from the metal magnesium and oxygen. It is infusible, slightly alkaline, and nearly insoluble in water. With water it forms a *hydrate* H_2MgO_2.

SODA OR SODIUM OXIDE (Na_2O) consists of two atoms of sodium to one of oxygen. It is a grey or white solid, resembling potash in appearance. It has a great affinity for water, dissolving readily in it, and in large quantity. It forms numerous salts with the acids, namely, nitrate of soda, carbonate of soda, &c., &c.

CHALK, MARBLE, LIMESTONE, AND CORALS are carbonate of calcium, that is, they consist of the binary compounds of calcite and carbonic acid.

SILICA (SiO_2) is the only compound formed by the union of oxygen with silicon. It is probably the most abundant of all substances whatever. It occurs in the form of *quartz*, *sand*, *flint*, and *rock crystal*, the latter being silica nearly, if not quite pure, and flint and sand only slightly intermixed with other bodies. (Also see table of the most abundant simple minerals, page 36.)

CARBONIC ACID GAS (CO_2) is composed of carbon and oxygen, in the proportion of one atom of carbon to every two of oxygen. It is an invisible or colourless gas, having a slight acrid taste and smell. It is not combustible, and not a supporter of combustion or of life. It is very poisonous. When carbonic acid is combined with the metals it forms a very large class of salts called *carbonates.*

ROCK SALT OR SODIUM CHLORIDE (NaC_2) is a compound of chloride and sodium.

POTASH (K_2O) is composed of potassium and oxygen, in the proportion of two atoms of potassium to one of oxygen. It is a white and caustic substance, readily combining with water, forming a hydrate. It melts when heated to redness, and volatilises at very high temperatures.

42. Terms, &c.—We will now give a short explanation of a few chemical names given to compounds, &c.

Acids.—An acid is a compound containing a certain quantity of hydrogen, easily replaceable by a metal when it comes in contact with it, either in a free state or as an oxide. It has also, generally, the property of changing vegetable colours to red.

Bases are compounds which, by reacting on acids, yield salts. The most important are oxides of metals. When brought in contact with an acid, their oxygen combines with the hydrogen of the acid to form water.

Silicates.—A silicate is a combination of an acid with one single base, when it is called *simple* ; or the acid is united to two or more bases, being then called *compound.* Minerals of this character—namely, *silicates*—are the principal constituents of rocks.

Oxides are compounds formed by the union of oxygen with other bodies.

Peroxide and Protoxide.—When a substance unites with oxygen in two different proportions, that which contains the greatest quantity of oxygen is called *peroxide,* and that which contains a less quantity *protoxide.*

Suboxide.—Many metals have the power of uniting with oxygen in more than the above two proportions. In this case the combination which contains a *less quantity* of oxygen than the *protoxide* is called a *suboxide,* and the *highest combination* of the substance with oxygen is called a *hyperoxide.*

Sulphides are compounds of the metals with sulphur, and form a very important class of compounds, presenting many analogies with the oxides. They are obtained either by heating the metals with sulphur in proportions, or passing a current of hydrosulphuric acid gas through a solution of salt. The sulphides of the metals of the alkalies and alkaline earths are soluble in water, but of other metals insoluble. The sulphides are a very important class of compounds, forming some of the most important ores from which the metals are extracted.

Pyrites.—The name given to the sulphide of iron.

Alkalies.—An *alkali* is a body that possesses properties the *converse of an acid.* It has a highly bitter taste; changes the blue juices of vegetables to a green, or the juices of vegetables which have been changed red by an acid back again to blue. Potash and soda are representatives of this class.

43. Compounds broken up into Simpler Forms.—As before stated, there are about 65 elementary substances. Of these only 17 occur extensively amongst mineral compounds. They are oxygen, hydrogen, carbon, sulphur, chlorine, fluorine, silicon, boron, potassium, sodium, lithium, barium, calcium, magnesium, aluminium, manganese, and iron. These, combined in various ways, compose the greater part of the earth's crust, and of its liquid envelope. By remembering or consulting the table of the atomic weights we have the proportion in which they combine among themselves, and also their atomicity, or power of *replacing*, sometimes called substitution by equivalents. These two facts are of great importance.

All rocks are composed of minerals, sometimes of one, when it is called a simple mineral, as limestone, consisting mainly of *calcite;* or it may be made up of two or more, as *granite*, being then called a compound mineral. With the exception of the following minerals, which are either elements or binary compounds—namely, carbon, quartz, rock salt, fluor-spar, iron pyrites, and hæmatite—the other rock-forming minerals are chiefly *silicates*, *carbonates*, or *sulphates*, the silicates being by far the most abundant, the carbonates next, and then the sulphates. There are nearly in every case accessory ingredients as well as the essential ones. The principal minerals are quartz, felspar, mica, hornblende, augite, clay, calcspar, and dolomite.

44. Decomposition of Compounds.—The general method of decomposing compounds is by means of chemical affinity. Thus, suppose we have a compound, AB, which we wish to resolve into its elements, A and B, we must add to the compound a substance C, which we know has a greater affinity for one of the elements than the other in the compound has—that is, C must have a greater affinity for A than B has, the result of which is that A and C combine, leaving B at liberty. Again, if we wish to liberate A, we must mix with the compound AB a substance, D, which has a greater affinity for B than A has. Then B and D combine, leaving A at liberty. Thus, for example, suppose we wish to separate carbonic acid from chalk, or calcium carbonate ($CaCO_3$), which consists of the two binary compounds, calcite and carbonic acid, if we take a bottle with sufficient water in it to cover a few pieces of the chalk, and add some acid—hydrochloric acid, for instance—carbonic acid will at once be evolved, the chalk having given up its carbonic dioxide (CO_2), which escapes free, the remaining atom of oxygen combining with the two atoms of hydrogen from the hydrochloric acid 2 (HCl), forming water (H_2O), whilst the calcium unites with the two atoms of chlorine forming calcium chloride ($CaCl_2$). By applying heat many compounds may be broken up into their constituent parts; thus, if a piece of *chalk* or *limestone* is strongly heated, it is decomposed into two binary compounds, *lime*, or *calcite*, and *carbonic acid* gas. The chief agent in decomposing rocks is carbonic acid, as water charged with this gas dissolves the majority of them. Thus, for instance—

45. Granite is composed of three minerals, quartz, felspar, and mica. Of these quartz is insoluble; but the acid will readily attack the felspar, which consists of silicate of alumina and silicate of potash, soda, or other alkali. The acid having a greater affinity for the alkali (potash, soda, &c.) of the silicate than silicic acid, forms with that alkali a carbonate which is soluble in water. The silicate of alumina, being unaffected by the acid, is set free as an insoluble clay [*Kaolin*], this decomposition yielding carbonate of potash or of some other alkali, according to the chemical composition of the silica and felspar, which are dissolved in the water, and clay. It is in this way that rocks get broken up by natural causes, carbonic acid existing largely in the atmosphere, in most waters (which is the next chief agent in breaking up rocks, &c.), and combined with minerals in a solid state, as in marble, which consists of lime united to carbonic acid. It is easy to understand that any one constituent of a substance being decomposed, the other constituents will be freed and readily removed by running water.

Kaolin, or *china clay*, as seen above, is derived from granite by its decomposition. Thus the felspar of granite consists principally of silicate of alumina and silicate of potash, that is silica and alumina chemically combined, and silica and potash chemically combined. Though both of these substances are insoluble in pure water, yet when water containing carbonic acid (CO_2) in solution flows over granite, the CO_2 combines chemically with the silicate of potash, which is insoluble, forming carbonate of potash. This being soluble in water is dissolved out by the water, and the silicate of alumina is reduced to a fine powder, which forms a white clay, which is used for manufacturing porcelain goods. It is found in China, France, Saxony, &c., and in England a large tract of this substance occurs near St. Austell, in Cornwall, on the south side of the granite range. (Analysis: Silica, 46·8; alumina, 37·3; potash, 2·5; peroxide of iron, 0·4; water, 13·0.)

Gneiss may also be broken up into the same substance as granite, namely, felspar, mica, and quartz; but the minerals are arranged in more or less thin layers. Fine examples of this rock occur in the Alps.

Syenite, another rock of this kind, may be broken up into felspar, hornblende, and quartz. *Protogine* is composed of felspar, talc, and quartz. *Mica-schist* consists of alternate layers of quartz and mica, the latter of which mostly preponderates. *Talc-schist* is composed of layers of quartz and talc. *Trachyte*, composed of sanidine felspar, and a litte mica or hornblende. *Basalt*, containing basic felspar, titanio-ferrite, augite, and generally olivine. *Felstone*, composed of acidic felspar and quartz. *Melaphyre*, composed of basic felspar, magnetite, augite, and generally chlorite. *Diabase* is similar to melaphyre. *Greenstone* or *diorite* consists of hornblende and felspar. *Dolorite* consists of augite and felspar.

It will be seen that *felspar* and *quartz* are contained in most of the principal rocks, common quartz being the most abundant of all minerals. We will now give the chemical composition of a few of the chief minerals.

Quartz is formed from pure silica (SiO_2).

Felspar, a silicate of alumina and potash (Al_2O_3, $3SiO_2 + KO$, $3SiO_2$), giving a percentage of silica 65·35, alumina 18·06, and potash, 16·59. A little soda always occurs.

Mica (potash) is a silicate of potash and alumina (KO, $3SiO_2 +$ Al_2O_3, SiO_2). A part of the potash may be replaced by lime and the protoxides of iron and manganese, and part of the alumina by the corresponding oxides of iron, manganese, and chromium. One analysis gives silica 47, alumina 20, potash 14·5, oxides of iron 15·5, oxides of manganese 1·75 per cent.

Mica (lithia), or *Lepidolite*, is a silicate of alumina, potash, and lithia, in combination with a fluoride.

Hornblende is essentially a silicate of magnesia, mixed with silicates of lime, iron, &c., the chemical composition of which varies much.

The minerals of the *Talc* group are hydrous silicates of magnesia and alumina.

Trachyte often contains disseminated crystals of glassy felspar, hornblende, a little quartz, and mica. Composition—Silica 67·09, alumina 15·64, potash 3·47, soda 5·08, lime 2·25, oxides of iron 4·59, magnesia ·98, oxide of manganese ·15, water, &c., ·83.

Clinkstone, or *Phonolite*, is composed of silica 56·28, alumina 20·55, potash 5·84, soda 9·07, oxides of iron and manganese 4·31, titanic acid 1·44, magnesia ·32, lithia ·05, &c.

Clay consists chiefly of silica and alumina, but is sometimes mixed with lime, magnesia, &c.

TABLE OF THE MOST ABUNDANT SIMPLE MINERALS.

PERCENTAGE ANALYSIS OF ROCK-FORMING MINERALS.

		Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Oxide of Iron.	Oxide of Manganese.	Lithia.	Water, &c.	Specific Gravity.
Quartz (when pure)..		100										
Felspar.	Orthoclase	65·35	18·06	..	..	16·59	..	..	..	..	..	2·6
	Albite	70·48	18·45	..	·55	..	10·50	..	..	..	..	2·5
	Oligoclase	63·50	23·10	·80	2·40	2·20	9·40	..	..	..	..	2·6
	Labradorite	53·70	29·67	..	12·13	..	4·50	..	..	..	..	2·6
	Anorthite	45·5	34·5	..	17	..	1	1	..	..	1	2·7
Mica (Potash Mica)..		47	20	..	..	14·50	..	15·50	1·75	..	..	2·9
Mica (Lepidolite)....		50·35	28·30	..	..	9·04	..	..	1·23	5·49	..	2·9
Augite		56·36	..	18·18	25·46	..	..	..	..	..	..	3·3
Hornblende		47	12	13	14	..	..	14	..	..	..	3·2
Talc		62·80	1	32·40	..	..	..	1·60	..	..	2·30	2·6
Chlorite		30·40	7	34	..	..	..	4·40	..	..	12·60	2·7
Antinolite		56·50	..	21	14·5	..	..	6	..	..	2	3
Serpentine		42·30	..	44·20	..	..	..	·20	..	..	13·30	2·3

From the preceding table it will be seen that the chief constituents of the rocks, &c., are silica, alumina, magnesia, oxide of iron, lime, potash, soda, carbonic acid, and water; and reducing these still further to their elements we find that *silica* is a compound formed by the union of silicon with oxygen; *alumina* by the union of aluminium with oxygen. *Magnesia* occurs in two states, sometimes as carbonate, in certain limestones, and sometimes as sulphate; hence it is composed of either carbon and magnesium or sulphur and magnesium. *Oxide of iron* is oxygen and iron combined; *lime* is oxygen and calcium; *potash*, oxygen and potassium; *soda* is obtained from a compound of chlorine and sodium; *carbonic acid* is carbon and oxygen combined; *water*, hydrogen and oxygen. From the above description we see that the elements which enter largely into the composition of rocks are very few, namely, *oxygen*, *silicon*, *aluminium*, *calcium*, *magnesium*, *iron*, *carbon*, *sulphur*, *chlorine*, and *sodium*, being in the order of their relative abundance, oxygen being the most abundant of all known substances, constituting at least one-third of the solid mass of the globe, eight-ninths of the water, and nearly one-fourth part of the atmosphere; it also exists in most organic substances. Taking into account the composition of the water of the earth and its atmosphere, the two gases, hydrogen and nitrogen, are also of primary importance, the former forming one-ninth of all waters, and the latter four-fifths of the atmosphere.

WATER: ITS COMPOSITION AND SEVERAL STATES.

48. **Water (H_2O), viewed chemically,** is a compound of hydrogen and oxygen. It can be separated into its elements by *analysis*. This is done by a decomposing apparatus, consisting of a trough, two tubes, two pieces of platinum foil, and connected with a galvanic battery. The trough is half filled with water and inserted, each over a piece of platinum foil, which is attached to a copper wire. The wires pass through the bottom of the trough to the outside, where they are connected with the wires of a galvanic battery. By the action of the battery, oxygen is given off in the tube joined to the copper or positive end, and hydrogen in the one attached to the zinc or negative end of the battery. It will be noticed that the hydrogen tube is filled in about half the time that the oxygen tube is filled, clearly proving that *water contains two volumes of hydrogen to one of oxygen.*

The composition of water may be also proved by synthesis, that is, by the direct combination of its elements, thus: fill a soda-water bottle *two*-thirds full of hydrogen and *one*-third of oxygen; then *wrap a towel well round it*, and apply a light; the gases will explode with a loud report, forming two measures of watery vapour.

We have shown that, by *volume*, water consists of two parts of hydrogen to one of oxygen, but by *weight* it consists of one part hydrogen to eight parts oxygen. Thus, in the table of elements, the atomic weight of hydrogen is 1, and that of oxygen 16. But there are two parts of H to one of O, hence the weight of H is $1 \times 2 = 2$, and of O $16 \times 1 = 16$, or as $1 : 8$.

It is the most important ("element," as the ancients called it) compound in the constitution of the globe, being, we might nearly say, everywhere. It always exists in the air in an invisible state, giving the blue appearance to the sky, and becomes visible in the form of clouds. It forms a constituent of all animal and vegetable substances, and also of the rocks and minerals which compose the crust of the earth. When pure and at ordinary temperature it is a fluid without taste or smell. In large bodies, as in seas and oceans, it has a peculiar bluish-green colour, but in small quantities appears colourless. When heated, under the ordinary pressure of the atmosphere, to the temperature of 212° F., at the level of the sea, water boils and is converted into steam. The higher we ascend the pressure of the atmosphere becomes less, water thereby boiling much sooner. Thus on the top of Mont Blanc, which is about 15,000 feet above the level of the sea, water was found to boil at 178° F., or 34° below its usual boiling temperature. What would be cooked at the sea-level might remain unchanged for hours in the boiling water at the summit of the mountain.

47. Expansion and Contraction of Water.—There is one point regarding water, in its different states and temperature, worthy of particular notice, and that is, its expansion and contraction follow a different law to all other bodies, with the exception of bismuth, which expand in proportion as they are heated and contract in proportion as they are cooled. If water be heated to its boiling point it will expand like other liquids, and if allowed to cool it will follow the general law, viz., contract, until it attains a temperature a little below 40° F., at which point it attains its *maximum* density, that is its *minimum* or least volume. If the water still continues to diminish in temperature it will now begin to expand until reaching the freezing point, or 32° F., and if cooled below this point, by being kept perfectly still, it will continue to expand, and in the act of freezing a sudden and considerable expansion takes place. Its effect may be noticed on water-pipes, &c.

The following are the changes which take place in the volume of water as its temperature is raised from 0° F. to 300° F. At 0° F. it is ice, and occupies, roughly speaking, about eleven-tenths the volume it will have at 32° F. when in a state of water. From 32° F. upwards it decreases in volume till reaching 39° F., when it attains its maximum density, that is, its minimum volume. As the temperature rises higher, the water again expands. The co-efficient of expansion increases as the temperature rises until it reaches 212° F., when the volume has increased to 1·043 volumes, and at 300°, if the pressure is so great as to prevent it becoming steam, it will occupy 1·1 volumes, but at the ordinary pressure of the atmosphere it would become steam at 212°, and occupy about 1,800 times the volume it did at 39° F.

If water followed the general law, and continuously contracted on cooling, it is evident that its weight, bulk for bulk, would get heavier and heavier; hence, as soon as the surface of our rivers was frozen and ice formed on the top it would sink to the bottom; then the fresh surface would in its turn freeze and another layer of ice sink; and this would go on, even if the winter was not severe, until our rivers, ponds, and lakes were converted into solid masses of ice, thereby causing destruction to their inhabitants. But such is not the case. It has been ordained by the Creator, in His infinite wisdom, that the water should expand, instead of contracting, below 40° F., thereby becoming lighter than the warmer water underneath, causing it to float on the surface instead of sinking, and helping to form a covering or protection to the water below and its inhabitants.

Water, as found on the earth, is seldom or ever absolutely pure, but contains more or less of various substances. Even rain water, the purest of all, contains small quantities of impurity, and that of rivers and springs much more. The water running through the ground dissolves more or less of the substances it meets with, and these substances sometimes become so abundantly taken up that the water acquires a strong taste and active medical properties. Such is the cause of the mineral springs so-called. Among the various substances found in water the chief are silica, alumina, salts of lime, magnesia, soda, potash, iron, manganese, atmospheric air, carbonic acid, nitrogen, &c.; in the sea are also found iodine and bromine.

Water may be either in a liquid, solid, or gaseous state. As water in its fluid state, rain, dew; solid state, ice, snow, hail; gaseous state, vapour, steam. These different states are all caused by different degrees of heat. (See "Cohesion, page 15; and for formation of rain, dew, snow, hail, &c., see page 185.)

Latent and Specific Heat of Water.—Water, like all other substances, has what is termed latent (hidden) heat; that is, *heat which is not perceptible to our feelings.* Thus, the temperature of ice is 32° F.; but if 144° of heat be communicated to it it will feel no hotter, but simply cause it to become a liquid, the 144° of heat being hidden in a latent condition in the ice. In ice there is altogether 1,116° F. of latent heat, 972° of heat being secreted when water is converted into steam.

The *specific heat* or *capacity for heat* of a body is the quantity of heat necessary to raise it through a certain number of degrees as compared with the quantity required to raise an equal weight of water through the same number of degrees. Of all substances *water* possesses the greatest capacity for heat; hence, when cooled through a certain range of temperature it parts with the greatest amount of heat. The high specific heat of water plays an important part in the economy of nature, the specific heat of water being 1, and of the air ·2374, or nearly 4·2 times *less* than that of water; therefore 1 unit of water in losing 1° would warm 4·2 units of air 1°; but water is also 770 times as heavy as air, so that, comparing equal volumes, a cubic foot of water in losing 1° would raise 4·2 × 770, or 3,234 cubic feet of air, 1°. We see from this the great influence which the ocean must exert on the climate of a country. The heat of summer is stored up in the ocean and slowly given out during the winter, Hence one cause of the absence of extremes in an island climate.*

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* Tyndall on "Heat as a Mode of Motion," page 148.

GEOLOGY.

RELATING TO THE EARTH'S CRUST.

48. The Crust of the Earth.—By the crust of the earth we are to understand the solid exterior as far as it is known to us by observation and inference. It is supposed that the earth was once in a state of fusion, and that having cooled by radiation, the outside cooling more than the interior caused a solid superficial layer to be formed. This consists of a variety of solid materials, to which the general term *rock* is given, which term includes not only stony and compact rocks like granite, limestone, &c., but soft and loose matter, as sand, clay, and gravel. The chemical character and composition of the chief of the rocks are given on page 36. We will now consider the *physical character and features of the chief of them.* The greater part of the rocks at the surface of the earth occur in regular beds—each bed maintaining an almost uniform thickness—appearing like piles of cloth piled upon each other. This class of rock is called *stratified;* but also denominated *aqueous* rocks, on account of being deposited from water when for the time the substances of which they are composed were either chemically or mechanically suspended; and *sedimentary,* because they are the accumulations of sediment carried in the sea by rivers. There is another class of rocks termed *unstratified, igneous,* or *plutonic,* being called unstratified because no traces of layers or beds can be detected, the rock forming merely a great mass of mineral matter; and igneous, or plutonic, because they have evidently been in a melted state through the action of very great heat.

SEDIMENTARY, OR AQUEOUS ROCKS.

49. The Aqueous Rocks may be divided into three classes, according to their mode of origin: (1) *Mechanically-formed* rocks—those formed mechanically from the ruins of existing rocks, such as conglomerate, sand, clay, shale, &c. (2) *Organically-formed* rocks—those consisting of accumulations of vegetable or animal remains, such as coal, peat, &c. (3) *Chemically-formed* rocks—those resulting from chemical means, as rock salt, gypsum, &c. They may also be divided into three classes, according to their composition, namely, as *arenaceous,* or sandy; *calcareous,* or limestone; and *argillaceous,* or clayey rocks.

(1) **Mechanically-formed Rocks** are merely fragments of rocks broken up by the action of frost, snow, rain, rivers, &c., and again deposited as sedimentary strata.

ARENACEOUS.—In this division we have *shingle, gravel, conglomerate, breccia, sandstone,* and *grit.* *Shingle* consists of pebbles of rock, not cemented together in any way, being rounded by the action of the stream or river, having their sharp angles and edges worn off. When the pebbles are smaller and mixed with sand it is called *gravel*, and *sand* when the fragments are very small. *Conglomerate*, or pudding-stone, is a rock consisting of rounded pebbles cemented together, the cementing material filling the interstices and rendering the whole a hard compact rock. If the materals are angular it is termed a *breccia*. The pebbles may consist of any substance whatever, and the conglomerate is named, according to the constituents, silicious, or quartzose, granitic, calcareous, &c., though mostly consisting of quartz, or some very silicious mineral, owing chiefly to the greater abundance of the silicious over other mineral matters that enter into the composition of the rocks. When the term conglomerate is used alone it is always understood to mean a rock composed of quartz pebbles. The cementing material may be either iron (ferruginous), sand (arenaceous), lime (calcareous), or clay (argillaceous). *Sandstone* is fine sand consolidated, but if the particles are coarse it is called *grit* or *gritstone*.

ARGILLACEOUS, OR CLAYEY.—The most simple class of this rock is *cla* , which results from the decomposition of felspathic rocks, &c., by the agency of acid waters. It is mostly found in an impure state, mixed with fine sand, flakes of mica, organic remains, &c. When pure it it is found to be a hydrated silicate of alumina, being found pure only in the case of *kaolin*. The clayey materials, by subsequent changes, become solid rocks; thus the agency of pressure alone having subsequently formed shale, slaty-shale, and clay-slate, each of which varies in texture and composition. There are a great many different varieties of clay, each receiving special names. *Pipe-clay*, so called from its being used in the manufacture of tobacco-pipes, is white and almost pure. It is sometimes termed potters' clay. *Fire-clay* contains very little iron, lime, or alkalies. It contains much silica, and often carbon; still being able to stand great heat without melting. *Bituminous-clay* contains bitumen. Other, containing oxides of iron, by which they are variously coloured, are termed *variegated*.

Shale is a laminated clay rock, which will split into thin plates along the original planes of deposition. When very hard, splitting into fine slabs, it is called *slate* or *clay-slate*. A very large proportion of the strata comprising the coal measures is constituted by this rock.

Marl is a calcareous clay, being composed of clay and carbonate of lime or carbonate of magnesia. It effervesces with an acid, and breaks when dry into small cubical or rounded fragments. When the rock contains less than one-half of clay it ceases to be marl, being then called an argillaceous limestone. There are many kinds of marl. When it contains much carbonate of lime it is said to be a *calcareous* marl; if it contains dolomite, with carbonate of lime.

a *dolomitic* marl; or with a minimum percentage of calcareous matter, an *argillaceous* marl; *arenaceous*, with much sand; *micaceous* with mica; *shell* marl, found at the bottom of old ponds, ditches, or lakes, formed from the decomposition of shells, &c.

Loam is a mixture of clay and sand, not so plastic as clay, and permeable by water.

Mud and *silt* are the materials of some form of argillaceous rock not cemented together, either clay, shale, loam, or marl, as the case may be; resulting from the waste of these rocks by running water and other natural agents of decomposition. The accumulations are formed by the particles, which are very small, being carried by running water, and deposited where the water is quieter, as at the mouths of rivers, &c.

COMPOSITION OF SURFACE SOIL.—Soil adapted to the growth of plants consists of two principal portions—the organic and the inorganic. The former, or *humus*, consists of decayed remains of animal and vegetable matter, but varies much in different soils. For instance, peaty soils contain from one-half to three fourths of their whole weight of this matter; but generally soils do not contain more than from 3 to 8 per cent, though stiff clayey soils, containing from 10 to 12 per cent, have been noticed. The *inorganic* portion of the soil consists of two minor divisions—the *soluble saline* portion, from which saline ingredients are obtained, and the *insoluble earthy* portion, which constitutes the great bulk of most soils, being seldom less than six-sevenths of the whole weight, the remaining seventh consisting of *organic* matter and *soluble saline* in about equal portions.

The constituents of this insoluble earthy portion, or the greater part of all soils, are *silica*, *alumina*, and *lime*; the first appearing in the form of sand; the second (alumina) mixed with sand, as *clay*; and *lime*, in the form of carbonate, as limestone, chalk, &c. According to Johnson, dry ordinary soil, containing one-tenth of clay, forms a *sandy soil*; if it contains from one to four tenths it is a *sandy loam*; from four to seven tenths, a *loamy soil*; from 73 to 85 per cent, a *clay loam*; from 85 to 95 per cent, a strong clay, fit for brickmaking; if it contains no sand, it wonld be a pure agricultural clay, or *pipe-clay*.

Very few arable lands contain more than from 30 to 35 per cent of alumina. Soils are called *marl* if they contain more than 5 per cent of carbonate of lime, and *calcareous* or chalky when more than 20 per cent—the soil appearing whitish, as on the south-east coast of England.

The *soluble saline* portion is made up chiefly of *common salt* (chloride of sodium), *gypsum* (sulphate of lime), *Glauber's* and *Epsom salts* (sulphate of soda and of magnesia), with slight traces of the *chlorides of calcium*, *magnesia*, and *potassium*, the *nitrates of* *potash*, *lime*, *soda*, *&c.*

(2) **Organically-formed Rocks** form a very important class, on account of their extent and thickness, and also their value, as in the case of coal, limestones, &c.

Limestones are of various kinds, being of various formations. Among the most important are the following: *Chalk*, *Metamorphic Limestone*, *Dolomitic* or *Magnesian*, *Oolite*, *Hydraulic*, *Siliceous*, *Mountain Limestone*, &c. Nearly all are formed by the elimination of the lime from the ocean by the agency of organic life, the shells having been ground to a powder by the action of the sea, and afterwards cemented together. Limestones are generally composed of calcite, that is, calcium and oxygen; but impurities, as silica, oxides of iron, clay, or carbon, are often mixed with it. Thus, the common limestone consists of two binary compounds; calcium and oxygen, forming *calcite*, and carbon and oxygen, forming *carbonic acid*. If the stone is burned the carbonic acid is expelled, and pure, or quicklime is obtained. Limestones present every variety of hardness and texture, from the soft *chalk* to the hard *crystalline* marble.

Chalk is a white earthy limestone, being made up of the minute shells of *Foraminifera*. It is one of the most pure, containing about 44 parts carbonic acid and 56 parts lime. It is very useful as a manure in improving the texture of the soil. *Magnesian limestone* consists of carbonates of lime and magnesia. Many of these stones appear to have been formed from limestones of true organic origin by the action of solutions containing magnesia. The *Dolomite* contains about 30 parts of lime, 21 magnesia, and 49 carbonic acid. The others do not contain so much carbonate of magnesia, varying from that in the dolomite down to only a few per cent.

Hydraulic limestone contains some clay and silica, and affords a lime, the mortar of which will set hard under water.

Oolitic limestone consists of minute spherical concretions, appearing like the roe of a fish—hence the name. It is mostly of a grey, greyish white, or yellowish colour, and, being easily worked, is largely used as a building stone; examples of which are Bath, Portland, and Caen stone. In the case of Portland stone, there is upwards of 96 per cent carbonate of lime, a trifle more than 1 per cent of carbonate of magnesia, and about 1 per cent of silica, a little oxide of iron, &c.

Coral or Mountain Limestone.—The coral reefs are built by what we may term an endless number of tiny animals called *polyps*, which take the lime from the sea, building these reefs and islands from the bottom of it, forming very large deposits of limestone. It is probable that their works are eternally going on; new islands continually emerging from the depths of the ocean. Coral consists of carbonate of calcium, with variable quantities of other salts of calcium and magnesium, and some organic matter. The red colour in some descriptions is said to be of organic and not mineral origin.

CORAL may be described as a calcareous marine production

secreted by polypi. The *Corallaria* is a family of corticiferous
polypiaria, in which the animals are hydroform, with internal
ovaria. They are formed externally of a living gelatinous, cretaceous,
and internally of a solid horny substance, concentrically laminated,
with a large base by which they are attached to other substances.
Corals are propagated by divisions, buds, and eggs. When the young
coral leaves the egg it is a minute oval body covered with multitudes
of little hair, like filaments, called cilia, by the aid of which it swims
about with great activity. After a time it sinks to the bottom, and
becomes fixed to the rock. Some corals throw out buds which grow
into branches. The white coral spreads over the bottom of the
ocean like turf, being able to divide and subdivide itself to an
extent. They are thus very similar in structure and habits to th
sea anemone.

The *sea anemone* on our coasts has no skeleton, being compose
entirely of jelly-like matter; when it dies it decays, leaving nothin
to mark its past existence. But in the coral polypi the stomac
and the mesenteries are hardened with lime or calcified, so th
when the animal dies the jelly-like portions decay and are washe
away, while the calcareous skeleton remains and accumulates wi
the skeletons of its predecessors, becoming firmly knit to the
on these others *build*, as it is called, still adding to the accumulatio
In this way these little zoophytic creatures, in the course of tim
form rocky structures reaching from the depths of the ocean to t
surface of the water. (See 63). Coral reefs, which are abunda
in the warm seas of the Indian and Pacific Ocean, have been form
by the gradual secretion of carbonate of lime by many generatio
of polypi. The coral polypi cannot live unless covered with wat
neither at a depth exceeding 70 fathoms.

Sea lilies, which are related to sea-urchins and sea-stars, furn
calcareous remains in some seas. These are fixed to the bottom
the sea, where they live, by long jointed stems consisting of carb
[illegible] of lime. Thick beds of limestone have been formed
accumulations of these stems.

[illegible] contains silica, diffused through the limest
[illegible] than ordinary limestone. On decomposition of
[illegible] water it leaves the siliceous residuum, forming rot
[illegible] used in brightening metals.
[illegible] found in layers of nodules in chalk, a mixture of silica
It is supposed to owe its origin partly to the presen
[illegible] *Chert* is a similar rock.
[illegible] GROUP.—In this group we include those w
[illegible] and resin, being chiefly products of vegetable accu
[illegible] combustible. The most important is coal, of w
[illegible] decomposition, varying greatly in composition, hard
[illegible] have separated the elements of co

volatile matter, charcoal, and ashes; others into carbon, oxygen, and hydrogen; others into charcoal, bitumen, and earth, according to the method of analysis. The chief varieties are as follows:—

Anthracite consists chiefly of carbon containing very little bituminous matter. It is hard, lustrous, and has the shining appearance of black lead. It does not soil the hand and emits little or no flame, but intense heat. Its specific gravity is about 1·4. It contains about 90 per cent of carbon, 3 per cent of hydrogen, the remaining 7 per cent consisting of oxygen, nitrogen, &c.

Bovoy coal, or *Lignite* (so-called from being found at Bovey, in Devonshire), is a kind of wood-coal (lignite). existing chiefly in the rocks of tertiary formation. It is of a dark-brown colour, and consists of wood permeated with bitumen, and often contains pyrites, alum, &c. This coal often shows the original woody fibre very little altered in appearance. When first dug out of the earth it is soft in consistence, but becomes harder rapidly on exposure. Its constituent parts are found to consist of 77·1 of carbon, 19·35 of oxygen, 2·54 of hydrogen, and 1 of earthy substance.

Cannel coal varies very much in appearance. It burns with a bright clear flame, like a candle (hence its name), and is a valuable coal for the making of gas. It does not soil the fingers when it is the glossy kind. Its constituent parts are 66 of carbon, 11 of oxygen, 8 of hydrogen, 1 of nitrogen, and 1 of earthy substance.

Pit coal is the ordinary coal of household use. It varies much in appearance and quality, some kinds *caking* when burnt, owing to the quantity of bitumen, or mineral pitch, which it contains.

Bitumous coal contains bitumous matter, more or less, varying from one-tenth to three-fifths of the whole. It burns with a bright flame, and is softer and not so bright as anthracite.

Splint coal is a very hard variety, obtained in large blocks. It is used chiefly for steam and furnaces. It contains about 80 per cent of carbon, 8 of oxygen, 6 of hydrogen, 1 of nitrogen, and 5 of earthy substance.

Coal is the product of the fossilisation of ancient vegetation, either on the places where it grew, or on those into which it had been drifted. By taking a thin slice of coal and examining it under a microscope, traces of vegetable tissues can in most cases be made out, especially indications of spore cases of club mosses and other flowerless (cryptogamic) plants. There may be noticed fern leaves, stems, barks, &c. Other facts going towards proving the vegetable origin of coal is its chemical composition, which is the same as wood, namely, carbon, hydrogen, and oxygen, together with some earthy substance which forms the ash in each case.

Peat or *Turf* is, like coal, of vegetable origin. It is formed chiefly from mosses in bogs and swamps, in which shrubs and trees often get buried. When vegetable matter is exposed to moisture and excluded from air chemical changes take place, the result of which is, the vegetable matter loses carbonic acid and water, becoming changed into *peat* or imperfect coal; losing more carbonic acid and water it becomes lignite or wood coal; still losing the same acid and water, in addition to a compound of carbon and hydrogen called marsh gas—which is the fire-damp met with by the miners—the lignite becomes coal; further losing more carbon and hydrogen it is converted into the hard glossy *anthracite.* In some layers of peat the actual species of moss may yet be determined. The growth appears to be still going on rapidly in some places, as, according to Leonhard, in Alt-Warmbrücher Moor, near Hanover, the turf or peat has been re-formed in fifty years, and during the last thirty years a layer from four to six feet thick has been in course of formation. The chief formations of this kind are the great bogs of Ireland, in which the roots, trunks, and branches of large trees, both pine and oak, are abundant; iron pyrites are also in abundance, very often causing spontaneous combustion and the formation of sulphates. Turf is also found in the tropics, as, for instance, at San-Panco, in the Brazils; and on the banks of the North Sea a species is formed from the accumulation of seaweed.

(3) **Chemically-formed Rocks (Calcareous).**—The greater number of the chemically-formed rocks are composed of carbonate of lime. Through the integrating power of water containing carbonic acid gas flowing through limestone rocks, some of the stone is dissolved, and when a portion of the gas escapes from the water the dissolved limestone is again deposited, mostly in beautiful crystals, called *stalactites,** that hang from the roofs and sides of caverns. The water slowly percolating through the rock, or calcareous bed dissolves its substance in its progress and appears as a drop upon the roof of the cavern, where it is suspended for a moment or so, during which time it loses carbonic acid gas and deposits carbonate of lime. The drop then falls to the floor of the cavern, carrying some portion of the dissolved limestone. The continuation of these drops form, on the floor of the cavern, either as a pinnacle, termed a *stalagmite,*† or as a *stalagmitic* sheet covering the floor of the cavern.

In districts where there is much limestone, the cold springs as they emerge from the rocks are often so highly charged with carbonate of lime that on reaching the open air they yield calctuff, or sinter, in the form of calcspar; and hot springs that of aragonite. Calctuff is usually a porous friable deposit, but sometimes its layers are firm enough to be used for building purposes, being very valuable from their lightness. *Travertine* is a similar rock, but usually more compact. A mass 30 feet thick has been formed in twenty years at the baths of San Fillippo. These springs have received the popular name of *petrifying springs*, on account of their giving a stony appearance to wood, moss, and other objects placed in them for some time, but it must be remembered that the object itself is unchanged, the carbonate of lime being deposited in a firm and solid state *on them*.

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* Gr. *Stalasso,* to drop. † Gr. *Stalagma,* a drop.

Gypsum is a chemical deposit composed of sulphate of lime. Some deposits owe their origin to the result of the evaporation of sea water, while others are supposed to be produced from the local conversion of limestones, by the agency of gases, or by infiltration. It sometimes occurs in beds, as in the neighbourhood of Paris—hence the name plaster of Paris, viz., ground gypsum—but mostly as irregular masses, intercalated in marls, appearing as veins or strings. It is also of frequent occurrence, as isolated crystals, or aggregates of crystals, in most clays, being then called *alabaster*.

Rock salt is also a chemical deposit, similar in origin to gypsum, namely, resulting from the evaporation of sea water, but especially of salt lakes, when there is no outlet (the evaporation being equal to the supply). The water though completely saturated with salt is continually receiving more; hence there must be a continual deposition of salt going on at the bottom. This rock is one of the few binary compounds, being composed of chloride of sodium. It occurs in large wedge-shaped masses in some localities, and sometimes in immense beds, as in Cheshire, and at Wicliczka, in Poland, and is always accompanied by gypsum.

Sulphur is found in a calcareous marl in Italy, varying in thickness from 4 to 31 feet.

METAMORPHIC ROCKS.

50. The Metamorphic Rocks are a group of rocks that were originally sedimentary or stratified, but have undergone a change of structure, or *metamorphosis*, by heat or pressure, the chemical composition remaining the same, but grouped together in different ways. This *metamorphism* does not always destroy the original character, but simply hardens the rock, as, for instance, sandstones hardened into hard rocks, called *quartzite*, limestones into *marbles*, clays into *slates*, &c.; but in some cases it does destroy the original character, rearranging the elementary substances of sedimentary rocks, converting them into rocks having a mineral composition similar to the igneous rocks from which they had originally been derived by chemical agencies, as, for instance, sandstones and clays may be converted into rocks whose composition is similar to granite, namely, quartz, felspar, and mica, and so on; but they may be generally distinguished, as they still retain more or less of their original stratification, and the minerals have a tendency to arrange themselves in layers, splitting easily along those planes, thereby differing from igneous rocks, which display neither of these features.

The chief metamorphic rocks are quartzite, mica-schist, gneiss, granite, crystalline, limestone, serpentine, &c.

Quartz rock, or quartzite, is a compact and granular rock, consisting of nearly pure quartz. It is not far removed from ordinary sandstone, the half-fused state of its component grains showing at once that it is a sandstone which has been altered by the action of heat, or of heat and water.

Gneiss consists of felspar, mica, and quartz, the felspar lamellar and the mica being arranged in lines, producing a foliated or schistose structure. This rock varies much in appearance. Sometimes the *laminæ* preserve their parallelism for great distances; but in other cases it is so obliterated that it cannot be determined from granite.

Mica-schist consists of alternate layers of mica and quartz, the mica preponderating. It readily splits into thin scales or *laminæ*, some varieties affording good roofing slates, such as *hornblende-schist*, consisting of hornblende and quartz. *Chlorite-schist* is a green slaty rock, in which chlorite is abundant, usually blended with quartz, though sometimes with felspar and mica.

Serpentine is a compact amorphous rock, consisting chiefly of silicate of magnesia. It is usually of a green colour, but sometimes variegated, resembling the skin of a serpent.

Granite, as before stated, is a rock composed of *quartz*, *felspar*, and *mica*. It is easily distinguished from other rocks by its mottled appearance. There seems to be a diversity of opinion whether this rock is of igneous origin, or simply the result of the extreme of metamorphism, though it is certain that many granites are true igneous rocks.

IGNEOUS OR UNSTRATIFIED ROCKS.

51. Igneous Rocks are all those which do not come under the definition of aqueous or metamorphic, showing traces of once having been in a state of fusion, or molten by heat ("igneous" meaning fire). They are mostly divided intp two classes, viz., volcanic and plutonic.

Volcanic Rocks are those which have been ejected in a melted state from volcanoes or fissures in the earth's crust, as lavas and ashes, which are good examples of igneous rocks—lava especially, as we can see it issue from the crater of a volcano as a molten stream, being afterwards turned into a hard rock. These volcanic rocks are divided into two sections—the felspathic or trachytes, having light colours and being of low specific gravity, containing an excess of silica, but poor in earthy bases and the oxides of iron; and the augitic or basaltic, having dark colours with high specific gravity, containing a large percentage of earthy bases and the oxides of iron, but poor in silica.

(1) *Felspathic* or *Trachyte rocks* are generally crystalline granular compounds. They are called trachyte on account of their rough texture, and are chiefly composed of acidic felspar, the specific gravity varying from 2·4 to 2·8. The grandest examples of these rocks are in Central and South America, in the chain of the Andes, of which they form the summits, the beds being sometimes from 14,000 to 18,000 feet thick, as off Chimborazo and the volcano Guangua-Pichincha.

Trachyte is usually of a greyish colour, and of a rough texture. It is composed of sanidine felspar, and mostly a little mica, or hornblende. When distinct crystals of felspar exist the rock is called trachyte porphyry. There are many varieties, such as *domite*, earthy and friable; *hornblende trachyte*, containing much hornblende in disseminated crystals; *slaty trachyte*, &c.

Pumicestone is very light, usually of a light colour, and containing about 70 per cent of silica. It has minute capillary and parallel pores, these pores being due to the escape of gases.

Obsidian is a volcanic glass, similar to coarse bottle glass, varying in colour from brown to greenish-black and black.

Clinkstone or *Phonolyte*, so called from its ringing sound when struck, is of variable composition, but is chiefly composed of glassy felspar with a zeolite in variable proportions. It is of a greyish blue and other shades of colour, generally splitting into thin slabs and containing zeolite disseminated through it.

Pearlstone is something similar to pitchstone, but not so glassy and more pearly. It is mostly of a greyish colour.

(2) *Augite or Basaltic Rocks.*—These rocks contain a great quantity of augite,* which prevails over the felspar, rendering them augitic rather than felspathic. They are of high specific gravity—namely, from 2·9 to 3·7—and range in colour from dark grey to black, the dark colour and high specific gravity being due to the presence of iron. The composition of these basalts include titano-ferrite (titanic acid and iron) and olivine (a silicate of magnesia and iron), as well as augite and felspar. The most important varieties are as follows:—

Basalt is a compact, and nearly or altogether a black rock, and usually composed of basic felspar, augite, titano-ferrite, &c. This rock often occurs in columns more or less hexagonal in section, examples of which are the basaltic rocks in Fingal's Cave and the Giant's Causeway.

Dolerite (deceptive) consists of labradorite and augite, with some magnetic iron. It has a crystalline and granular texture, and is of a black or greenish-black colour. Specific gravity, from 2·85 to 3·1. The variety anamesite is a similar rock but finer grained, being intermediate in texture between basalt and dolerite.

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* A green mineral, composed of silicate of lime with magnesia and iron.

Leucitophyr, or leucite rock, of a dark grey colour, fine grained, cellular, consisting of augite and leucite, &c.

Ashes are merely fragments of the foregoing rocks which have been reduced to various degrees of fineness. When they appear as cinders they are called *scoriæ*; when the lava, in its journey through the air, takes of a spherical form more or less, they are *bombs;* when cemented together in beds or masses, *tuff;* or as small stones, or fragments of ejected rock, *lapilli*, &c.

52. **Plutonic Rocks** are supposed to be of igneous or aqueo-igneous origin, formed under great pressure—having been melted and afterwards cooled and crystallised, but very slowly, in the depths of the earth. They consist of crystallised silicates, with or without free quartz, and other minerals—such as iron pyrites, &c.—in smaller quantities. The chief of this group is *granite*.

(1) The ordinary kind consists of orthoclase quartz and white mica, disseminated in nearly equal proportions. The felspar is lamellar and the texture mostly granular, sometimes being finely grained and at other times coarsely grained. Its colour is either greyish or reddish, depending chiefly on the colour of the felspar. There are several kinds of granite, some of which are—*Syenite*, which is a hornblende granite, consisting of a felspar, quartz, and hornblende, the felspar lamellar often predominating. *Pegmatic* consists of lamellar orthoclase felspar and quartz, often arranged in broken lines. *Eurite*, being blended into a finer granular mass, though of same constitution as granite. *Protogine* (first produced) is of the same composition, with the exception of talc in the place of mica. Granite and granitic rocks are abundant in some parts of the British Isles, constituting the greater part of the Grampians in Scotland, and the mountains of Cumberland, Devon, and Cornwall, also the Wicklow Mountains, in Ireland, &c.

(2) Those generally classed as *trap-rocks*—from the Swedish *trappa*, a stair—these rocks being supposed usually to assume a step-like form, though the name trap with the Swedish geologists simply meant any compact dark-coloured rock composed of felspar with augite.

Felstone is a compact, hard, flinty-looking rock, composed of acidic felspar and quartz. When this rock contains crystals of these minerals it is termed porphyry.

Diorite consists of felspars, hornblende, and sometimes mica, being very nearly of the same constitution as granite, which it resembles very much, sometimes passing into that rock by metamorphic action. It is one of the most important and widely spread of rocks. *Green-*

stone is a variety of this rock, in which green or dark-coloured hornblende predominates. *Porphyrite* consists of a matrix of basic felspar, containing felspar crystals, varying in colour from grey to dark purple. If such rocks as these contain mica as an essential it is called *minette* (Fr., pussy); if quartz, a *quartz porphyry*; if augite, a *basalt* or *dolerite.*

Kersantite is a minette, or micaceous diorite, consisting of magnesian mica, hornblende, &c.

Melaphyre is composed of basic felspar, augite, magnetic iron (magnetite), and sometimes chlorite,* in a glassy base. It is of a black or dirty-green colour. *Diabase* is a similar rock, though differing a little in the species of the felspar. *Pitchstone* is a compact glassy kind of rock, somewhat like solid pitch in texture, its colour varying from nearly white to a dirty or blackish green.

INTERNAL HEAT OF THE GLOBE.

53. We will now consider the **observations and evidences tending to prove the internal heat of the globe** and that the heat increases the deeper we descend. That the earth was in a molten state at an early period of its existence, is strongly affirmed by its spheroidal shape, as any matter in a fluid state rotating on its axis would have a tendency to fly off from the equatorial region, bulging out there, on account of its centrifugal force, and flattening or compressing it about the axis of rotation. Active volcanoes point to the existence, at some unknown depths, of enormous masses of intensely-heated matter, which in many cases is in a constant state of fusion (lava).

From observations made in mines and artesian wells, in France, England, Prussia, and elsewhere, it is assumed that below a depth of about 70 feet—the stratum of variable temperature—the temperature increases on an average about 1° F. for every 60 feet in depth. The stratum of variable temperature is the crust of the earth as far down as the effects of the sun prevail—namely, about 70 to 80 feet—when we reach a constant temperature. Above this line the heat varies with the seasons. In the Astley Coalpit, Dukinfield, near Manchester, the line of constant temperature was reached at the depth of 71 feet, being continually 51° F. At the bottom of the pit—namely, 2,080 feet below this line—the temperature is constantly 75°, showing an increase of 1° F. for every 86·6 feet. Observations taken at Rosebridge Colliery, near Wigan, on the rocks themselves, give the increase during the sinking there to be 1° F. for every 54·5 feet descended, the temperature at the depth of 2,418 feet being as high as 93·5° F.

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* Chlorite is a mineral composed of silica, alumina, and magnesia, of a greenish colour.

The water in artesian wells is warmer than the mean surface temperature, always increasing with the depth, the water in one at Grenelle, near Paris, whose depth is 1,800 feet, being constantly at 81·7° F.

The density of the earth affords another argument in favour of a high internal heat. The average density of known rocks is about 2·5 times that of water, and that of the whole earth about 5·5; but as the density increases with the depth, so much that water would be as heavy as mercury, or more than twice the specific gravity of the whole earth, at a depth of 400 miles, it is evident that if the interior of the earth be composed of such materials as occur at the surface, they would have a higher density still than this. Hence it is inferred that they must be greatly expanded by some expansive force or other, and the only force we know of capable of producing this expansion is heat. The chief facts regarding internal heat may be briefly expressed as follows: (1) The earth has an internal temperature which increases everywhere with the depth. (2) The rate of increase varies in different places; but in this country the average increase is about 1° F. for every 60 feet in depth below the line of variable temperature.

Chemical theories have also been put forth to account for the existence of internal heat, and consequently of volcanic action. The following may be mentioned:—

Lemery attributes volcanic eruptions to the spontaneous combustion of materials existing near the surface, as sulphur and iron, beds of coal, &c. *Brieslav* supposes that volcanoes may arise from the mass of petroleum collected in cavities in the earth and set on fire, the combustion arising from the presence of certain combinations of phosphorus and sulphur. To substantiate his theory he calls attention to the conflagrations that occur in coalmines, being set on fire by the presence of some body which must be spontaneously combustible. Other theories are put forth, but these two will be sufficient to give an insight into some of the supposed causes.

54. The Nature of the Interior of the Earth.—It has long been inferred that the globe consists of a melted fluid core, enclosed in a cool and hardened rind or crust; but this notion has recently been discarded. The principal objections that have been brought to bear against this theory are briefly as follow: (1) If the inside be liquid it must obey the sun and moon in their tide-producing action, causing corresponding undulations of the solid crust, especially at new and full moon. These certainly would have been perceptible if they existed. Sir William Thomson is of opinion that it is extremely impossible that any crust thinner than 2,000 or

2,500 miles could maintain its figure with sufficient rigidity against the tide-producing forces of the sun and moon. (2) If the volcanoes proceeded from one continuous fluid mass the lava would obey the well-known fluid law, standing at the same height in all cases, which is very far from the case, &c.

The more correct notion, and that which is most generally received now, is that the earth is a solid. In support of this theory it is supposed that the solidification of the earth commenced at its centre, and also at a later period at its surface by radiation. So that there would appear to be two zones of solidification, and between these we may imagine the space to be of honeycomb structure, containing the last remnants of the fluid in detached masses, which will account for the volcanic phenomena — those which have become extinct, probably through the fluid in the cavities becoming gradually solid, and others outbursting, perhaps due to an increased temperature brought about by some cause, such as the transference of the fluid from one part to another through this honeycomb structure.

VOLCANIC PHENOMENA AND DISTRIBUTION OF VOLCANOES.

55. **The Phenomena of Volcanoes** are the great commotions taking place under ground, ejecting through vents *volatile bodies*, melted rock (called *lava*), with fragments of solid rocks, as *cinders* and *ashes*, and sometimes *steam* and *sulphuretted hydrogen*. The funnel-shaped depressed central openings through which the material is emitted are called *craters* (cups). Volcanoes are termed *active* when they are really in action, and *extinct* when they have ceased to be active, but may become so at any time. There are also volcanoes which occur beneath the sea. These are called *submarine* (under the sea), and those on land *subaerial* (under the air). Volcanoes mostly appear in the form of cones, to account for which two theories have been put forth, namely, the *elevation theory*, and the *eruption theory*. According to the first it is supposed that the cone is formed by the swelling-up of the level lying rocks into a bubble-shaped mass, finally bursting at the top. These are known as craters of elevation. The eruption theory, however, is the one most generally accepted—namely, that the cone is the result of the ejected materials accumulating round the crater as a centre.

Eruptions.—An eruptions is, in most cases, preceded by hollow rumbling noises, like thunder, and sometimes by earthquakes, dense black smoke hanging in vast heavy masses over the mouth of the crater. The snows that have been lying at the top melt, often causing sudden and destructive torrents, as in the case of the immense bed of snow upon Cotopaxi, in the Andes, being melted in one night (1803); and in 1797 the melted snow from Tunguarajagua, mixed with mud, &c., filling the valleys beneath to a depth of six hundred feet. Flashes of flame, and enormous quantities of ashes, are projected, and often carried by the wind to an incredible distance. In the case of the eruption of Coseguina, in the Andes, ashes fell at a distance of 1,200 miles. Red-hot stones, of great weight and size, are shot out of the craters like shells from an immense cannon, and are known as *bombs*. One of these, weighing ten tons, was thrown by Cotopaxi, in South America, a distance of nine miles; the flames rose to the height of more than 1,000 yards from the crater, and the noise was heard more than 600 miles off, the ashes darkening the air for days. The lava flows down the sides of the mountains in immense streams. It is at first nearly of the consistency of honey; hence its speed is not generally great, varying from two miles an hour to that distance in from one to ten years. The amount projected at one eruption is enormous, the greatest on record being from Skáptä Yokul, in Iceland, in 1783, when it flowed in two streams, 50 miles in one direction and 40 in the other, the breadths being 15 and 7 miles respectively, and averaging 100 feet deep. So that its immense volume might be better comprehended, it has been calculated that it would cover London with a mountain equal in height to the Peak of Teneriffe, or more than 12,000 feet high. The volcanoes of South America, and many others, generally discharge no lava, but simply ashes.

56. Distribution of Volcanoes.—The chief fact regarding the distribution of volcanoes is their nearness to the sea, all—with the exception of two or three in Central America, and two or three in the range of Thian-Shan, in Central Asia—being near to the sea. Another striking feature is the tendency to a linear arrangement, as, for instance, in the great chain of the Andes and Asiatic Islands. Out of 407 active and extinct volcanoes, 365 are of this description, the remaining 42 being what is termed *central*, or central systems, consisting of a group of volcanic vents surrounding one principal cone, as those in the Canary Islands, with the central Peak of Teneriffe.

The number of active volcanoes is variously estimated by different geographers, but according to Professor Ansted they are distributed as follows:—

POSITION OF VOLCANOES.		PRINCIPAL CONES.
Atlantic Ocean	Northern part	10
	Central part	10
	Southern part	3
Gulf of Mexico—West India Islands		10
Mediterranean Sea and coasts		5
Red Sea and African coast adjacent		2

POSITION OF VOLCANOES.		PRINCIPAL CONES.
Indian Ocean—West side		3
Asiatic continent		5
Asiatic coasts and islands	Southern part	75
	Eastern part	110
Eastern Archipelago and Pacific Ocean		16
America	Northern series	45
	Central series	45
	Southern series	54
Antarctic Land		3
Total		396

From the above table we see that the greater number of active volcanoes belong to the islands and shores of the Pacific, forming, as it were, a *belt* to the basin of this ocean, and being at least two-thirds of the whole number. This *band* or *belt* commences in the New South Shetlands, in lat. 62° 55′ S., where there is an active volcano; passing from there to Tierra del Fuego, in Patagonia, and then on to the Andes, there being upwards of 30 in Chili, six or seven in Bolivia and South Peru, 16 or more about Quito, in Ecuador, nearly all above 14,000 feet high, the chief of which is Cotopaxi (18,876 feet). Proceeding through Central America the line continues still northward by the volcanoes of Mexico, where there are seven or more, passing through California, Oregon, and British Columbia, the Aleutian Islands, in which there are 23 volcanoes in a distance of 900 miles, carrying the chain across to Kamtchatka, on the Asiatic side of the Pacific, passing through the Kurile Islands, where there are 16, through the islands of Japan (24), through Formosa, the Philippines (15), to Moluccas, where it sends off a branch to the south east, through New Guinea, to New Zealand; but the line of greatest activity continues westerly, through Java (45), to Sumatra (19), and afterwards in a north-westerly direction to Barren Island, in the Bay of Bengal. *In the Indian Ocean* there are a few, namely, those in Madagascar and the Isles of Bourbon, Mauritius, &c.

Volcanic mountains, *central systems*, are found in the Sandwich Islands, Marquesas, Society Islands, Friendly Islands, Feejees, Iceland (24), Azores, Canary Islands, Cape Verde Islands, Ascension, Trinidad, Italy, Sicily, Mediterranean Sea, &c.

The grandest examples of volcanic action are those in the Andes, next to which come those of Kamtchatka. Java contains more volcanoes than any area of the same size in the world. Of those in Europe the chief centres occur in the Mediterranean, namely, Vesuvius, Etna, and Stromboli, the last emitting fire and lava almost continuously—so much indeed that it is styled the lighthouse of the Mediterranean. Another of this description is *Hecla*, in

Iceland. To ***volcanic energy*** may be attributed the elevation and subsidence of lines of coast, and the formation of numerous islands in different parts of the globe. Even hills of considerable size form in a short period, as, for instance, Mount Jorullo, west of the city of Mexico, which in 1759 rose out of the plain (and several square miles around it), in two days being raised 1,375 feet. Its height is now 4,265 feet.

Solfataras are places where sulphur vapours escape and incrustations of sulphur form, though the proportion of this mineral is small. Sometimes this gas also escapes from holes and fissures in the sides of the craters, the holes being then termed ***fumeroles*** or smoke vents.

57. Extinct Volcanoes.—Every large region on the globe bears marks of volcanic action in times past. The volcanoes are hence said to be *extinct*. The seat of volcanic activity seems to have often shifted during the geological history of our planet. In some places, as in Auvergne in France and the Eifel in Germany, there are yet to be seen cones and craters and descending currents of lava, and other evidence testifying to the fact that active volcanoes have been in those districts at some time not very far back geologically speaking. While in other places, as in the British Isles for instance, the volcanic rocks have been so long exposed to the waste of the elements that no actual crater is now to be seen. There is ample evidence that a chain of volcanic islands extended from the North of Ireland to Iceland, and formed the hills of Antrim, Mull, Eigg, Skye, Faroe, and the older parts of Iceland. The present ones of Iceland are probably remnants of this band. Abundant traces of past volcanic agency are to be found in the basaltic wonders of Staffa, in Salisbury Crags near Edinburgh, and in numerous other localities.

58. Hot Springs or Geysers.—Springs of boiling water are to be found in some of the volcanic regions, the waters of which are mostly of a mineral character. In Iceland there is a group of fifty or more, called geysers (roarers), situated about 36 miles north-west of Mount Hecla. The two largest are the Great Geyser and the New Geyser, about 100 yards apart, the former being 70 feet wide at its greatest diameter and four feet deep, situated on the top of a mound 15 feet above the adjoining ground. In the centre is a pit six feet wide and 80 feet deep perpendicular, up which the boiling water constantly ascends. At intervals of a few hours the water rises a little above the surface and then subsides, but is thrown generally once a day to a height of 60 to 80 feet, appearing as a lofty column of hot water. Sometimes these springs throw the water to a height of 200 feet, covering the country around with volumes of steam. Just previous to an eruption of this description the water was found at the bottom of the central pit to be more than 260° F., or 48° above the boiling point, though generally the temperature is from 180° to 190°. Hot springs occur at Bath and Buxton, in this country, the temperature of the water being 82° and 115° respectively. The propulsion of the water is supposed to be the sudden production of steam in subterranean chambers. Geysers are found in New Zealand and California; also hot springs in the Azores. When the ejection of water is in a muddy area it forms *mud volcanoes* or *mud cones*, examples of which occur in California, Iceland, on the Caspian, and along the northern slopes of the Himalayas into China.

59. To account for the Spasmodic Action of Geysers several theories have been put forward. Thus, according to some, the cause of the *intermittent* explosions is thus explained. The boiling point of water depends upon the pressure. The greater the pressure on the water the higher the boiling point. The boiling point of water deep down in the tube is therefore higher than it is near the surface. As soon as water reaches its boiling point it is at once converted into steam. Now suppose water at a temperature of $(100+x)^\circ$ C, is at a certain depth in the tube where the boiling point is $(100+x+2)^\circ$ to be raised by the accumulation of water to a point where the boiling point is $(100+x-1)^\circ$, the water being at $(100+x)^\circ$, or 1° higher than the boiling point at this place, will be converted to steam, which will expand and force the column of boiling water above it. The water cooled by its eruption and falling back into the basin, will be once more heated, and after a time again expelled, producing the periodical eruptions.

Another theory put forward is—*The action of water upon vast beds of pyrites.* In geyser regions extensive beds of sulphur and pyrites are to be found. Decomposition of the latter is readily produced by the agency of water and air, and in the process of decomposition great quantities of heat are evolved. The heat produced by this action is sufficient to raise an additional quantity of water in the form of steam, which makes its way to the surface, and is there emitted through the different clefts in the rock. The character of the soil and rock in the geyser districts, both of Iceland and North America, strengthens this theory, and so do the other surroundings. In all cases there is free access of water, for sulphur is widely dispersed, and the steam jets are invariably accompanied by large quantities of sulphuretted hydrogen.

Sir George Mackenzie puts forth the following explanation of the geysers. He is of opinion that the tube of the geyser is in communication at its lower extremity with some subterranean cavern, the neck of which is much contracted. These caverns, *partially* filled with water by percolation through the soil above, are heated by heat-conducting rocks, which derive their heat from the internal heat of the earth. The water would thus be boiled, and the steam generated would accumulate in the space above the water until it gained an elastic force sufficient to blow the water out of the tube, or failing this, the steam escaping round the neck of the cavern, by pushing the water before it, would condense in the cooler water of the tube, thus causing only a rising and falling of the water in the basin above as seen in some of the geysers.

No doubt but that the first theory is the true one, but we give the other theories, and leave it to the student to bring forward such arguments as he can, either in support of or against each theory.

60. Earthquakes.—Earthquakes and volcanoes are evidently intimately connected, as the greatest number of earthquakes occur in volcanic districts; but still they are not confined to these districts. These earthquakes consist of commotions, more or less violent, of the surface of the earth. There are several kinds, namely, *tremulous*, *vertical*, *horizontal*, and *rotatory*. The *tremulous* is the least destructive. *Vertical*, or perpendicular; a mine-like explosion, acting from below upwards, a case of this kind occurring at Riobamba (1797), when the bodies of the inhabitants were thrown on a bank nearly 100 feet high. *Horizontal* or *undulatory*, resembling the undulations of the waves at sea, progressing at a speed of 20 to 30 miles a minute. *Rotatory* is the most destructive kind and most rare, the vibrations, following several cross directions, causing a whirling movement of the earth. The earthquake of Lisbon, in 1755, and that of Calabria, in 1783, were of this character. The direction of the concussions is generally in a linear direction, as that of Guadaloupe, in 1842, which extended a distance of 3,000 miles, with a breadth of 60 to 70 miles; but sometimes circular, as at Calabria (1783), when all the villages within a radius of 22 miles were destroyed, and 100,000 persons perished, and fields even were found to have changed places.

The *most destructive* earthquake experienced in the Old World was that of Lisbon (1755), when 60,000 persons lost their lives, the shock being felt over an area more than three times the ize of Europe—rocking the waters of Lake Ontario, in North America, causing the Atlantic to overflow many of the West India Islands, the waves rising 60 feet above their usual level at Cadiz, and even 8 to 10 feet on the Cornish coast.

61. Earthquake Bands.—The regions where earthquakes occur are generally the same as the volcanic districts, the most noted in America being along the east, on the west side of the *Andes*. Severe shocks are also felt in the Alleghany Mountains. In Europe the chief seats are in the district of the Mediterranean, though there is an important one extending from Portugal to the Azores, Canaries, and the district of Central Asia, stretching from these places as far as Lake Baikal. The district of Iceland also includes the North of France, Great Britain, Denmark, and Scandinavia. Africa experiences very few earthquakes, with the exception of the extreme north and south; and Australia very few, those being on the west, but New Zealand frequently.

62. Causes of Earthquakes and Volcanoes.—It is believed that both earthquakes and volcanoes are due to the same cause, but what this cause is does not seem definitely known. The ancient philosophers were of opinion that their origin was due to some sudden explosion in the internal parts of the earth; others supposed something in the air caused them, on account of earthquakes being preceded by a calm and serene atmosphere. The geologists of the present day are of opinion that the *chief cause of volcanic eruptions and earthquakes is the expansive force of steam.* The earth, as before stated, is supposed to be solid, with the exception of large cavities or lakes of molten lava. The water of the ocean and land, sinking through the crevices, constantly finds its way down, and is then converted into steam, whose enormous pressure is most probably the cause of both volcanic energy and earthquakes. Mitchell, in his work on earthquakes, expressed a somewhat similar opinion, attributing them to subterranean fires, whose existence in nature (he writes) we have certain evidence of, and which are capable of producing all the appearance of these actions. If a large quantity of water should be let out upon these fires suddenly, it may produce a vapour whose quantity and elastic force may be fully sufficient for that purpose. It is believed that the seat of the disturbing force is never above thirty miles below the earth's surface. Mr. Mallet considers earthquake movements to be due to the strain or tension of the rocks, caused by vapours confined beneath the crust. By experiment it has been found that rocks are capable of extension. Thus Portland limestone can be extended without a fracture $\frac{1}{1879}$ of its whole length, or about three feet to a mile. Respecting the source of internal heat which produces the vapour, he believes that it is due to the friction of the rocks, caused by shrinkage in different parts of the earth's crust. The process of the earth gradually cooling is generally believed to be still going on, and, therefore, as it cools it contracts; and, according to Mr. Mallet, one-fourth of the amount of contraction now actually taking place would amply account for the entire seismic energy of the earth. Of all theories put forth, this seems the most likely to be the correct one. We here have an example, on a large scale, of *motion converted into heat*, the heat causing volcanoes and earthquakes, so that these are the *effect* rather than the cause of the movements in the earth's crust.

The *phenomena* attending earthquakes are—the elevation and depression of great areas of land, violent oceanic movements, the opening of great fissures (as in Calabria), the swallowing up of whole cities and even mountains, drainage of lakes, displacement of loose rocks, destruction of life on sea and land, and the production of forced waves in the ocean.

63. Determination of Effect of Earthquake Shocks.—Mr. Mallet, who has devoted great attention to the study of earthquakes, shows that all the effects produced by the phenomena are the natural result of the action of vibratory motion upon materials differing in shape, position, and degree of rigidity. He also endeavours to prove that it is possible, from the effects of earthquakes, to determine—

(1) The depth of the impulse which gives rise to the shock;
(2) The angle at which the earthquake wave emerges from that centre;
(3) The rate of movement of the wave; and
(4) The velocity of the shock.

Thus, the force generated by an earthquake consists of a wave or waves of elastic compression. This does not operate in a horizontal direction, but comes up to the surface obliquely from below, except in the case of the point immediately above the *focus* or *centre of impulse* of the shock. The earthquake waves are propagated in a series of spherical shells. The shock will evidently be first felt at the point vertically above the focus. The line joining this point with the forces is called the *siesmic*[*] *vertical.* These vibratory waves will reach other points of the surface a few seconds later, emerging from the ground in a direction which will form a less and less angle with the horizon as the distance increases from the seismic vertic. This angle is termed the *angle* of *emergence*, and a line drawn from any point in the surface to the focus is termed the *path of the wave.* The points on the surface reached simultaneously by the waves would form a series of concentric circles. These are called *coseismal circles*, and the points *coseismic points.*

The amount of movement communicated depends upon—

(1) The force of the shock, called the *seismic* force.
(2) The depth at which the shock is given.
(3) The elasticity of the rocks through which the vibration passes.

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[*] Greek, *Seisma*—an earthquake.

The earthquake wave travels with great velocity, dependent upon the elasticity of the rocks through which it passes, and is generally about half the rate at which cannon shot travels. The transmission of this motion is very similar to the transmission of wave motion on the surface of a pond of still water, caused by a stone being thrown into it. Each particle vibrates, and transmits the vibrations in all directions. The distance through which each individual particle moves is termed the *amplitude* of the wave. This never exceeds a few feet. The more rapid this movement the more destructive are the effects of the earthquake.

By studying the great earthquake in Calabria in the year 1857, it was calculated to have its centre of impulse at about 5·3 miles in depth, and the earthquake at Riobamba in 1797 at 30·6 miles. Mr. Mallet considers that the greatest possible depth at which an earthquake can be formed never exceeds thirty miles, and the average depth of *foci* about fifteen miles.

THE EARTH'S CRUST.

Slow Upheavals and Subsidences of the Earth's Crust.—That the level of the earth changes is evident from the fact that the greater portion of the land consists of strata composed of waste matter accumulated at the bottom of seas that have existed where the rocks are now found; and even our own coasts, forests, &c., have been found submerged. We have evidence that slow upheavals and subsidences are constantly going on over large tracts of land. The shores of Scandinavia, on the Baltic, afford strong testimony of this, as in the southern extremity the land is gradually sinking beneath the sea, while at the north, in the district of the North Cape, it is rising as much as five feet in a century. These facts regarding the elevation have been drawn from the appearance of the rocks above water, which were always formerly submerged, channels becoming shallower, and the occurrences of sea-beaches at elevations above the sea-level, which are termed *raised beaches*, several of which are found on our own shore, namely, in Sussex, Devon, and Cornwall—the opposite appearances showing the depression. Another instance of slow depression is afforded on the south-west coast of Greenland, where the shore is slowly subsiding, buildings being submerged along the coast.

Facts have also been discovered lately adding to the existing evidence that there is a rise of land going on in the southern circumpolar regions. In Australia, Tasmania, and New Zealand the phenomena are remarkable. For instance, in one place certain lakes and a river disappeared, owing to the rise of the land. In another place, on the western coast of New Zealand, the high-water mark of the year 1814 is now 200 yards inland. Many other facts might be cited. According to Mr. Howorth, in his communications to the Royal Geographical Society, they prove that the masses of land round about the south pole are at present "areas of upheaval," and that the earth's periphery is being stretched or extended in the direction of the shortest axis. One remarkable fact to be noticed in all this area—exhibiting so many signs of rapid upheaval—is the marked absence of volcanoes, as in the entire circle there are only the two or three in North Island, New Zealand, and those in Tierra del Fuego.

Many other instances might be mentioned bearing similar testimony. The most striking proof of the depression of large tracts is afforded by the distribution of coral reefs. These reefs are of three chief kinds—*fringing reefs*, *barrier reefs*, and *atolls*. The coral polyps, or reef-builders, are unable to live in water when the depth exceeds 30 fathoms. Hence these reefs cannot commence to form in the deep ocean, as they must have land within a few fathoms of the surface to start on. *Fringing reefs* are of no great thickness, and skirt the coast at a small distance from it, as the reef around the Island of Mauritius, which lies half a mile from the shore in very shallow water. *Barrier reefs* are much greater reefs, occurring quite away from the shore, generally running parallel to the coast, the vertical thickness of the formation in some cases being quite 1,000 feet. Examples of this kind are—(1) The Great Barrier which extends in a broken line along the north-east coast of Australia, at an average distance of about 30 miles, though in some parts from 50 to 70, the depth of water being from 30 to 60 fathoms, and outside the reef the depth in some places exceeds 300 fathoms. (2) The reef off the west coast of New Caledonia is 400 miles in length, and distant from the shore about 10 to 16 miles, the depth on the side away from the shore exceeding 1,000 feet. *Atolls* are ring-shaped reefs enclosing a lagoon of still water. The outer slope of the reef is very steep, as in the case of the Cocos Atoll, where no bottom was found at a depth of 7,200 feet. The water in the lagoon is shallow. In the above-mentioned island it varies from three to ten fathoms in depth. From the known fact of the coral builders being unable to live below 90 or 100 feet, it is evident that the bottom on which these barriers and atolls were commenced building must have been gradually sinking for ages. According to the theory of Mr. C. Darwin each atoll and barrier reef began as a fringing reef round an ordinary island. First the insects built the *fringe reef* close to the shore, the island slowly sinking, leaving a smaller surface and causing more space between it and the reef—the insect still building upwards, forming a *barrier reef*, the land continuing slowly sinking until the island has entirely disappeared beneath the waters; at the same time the reef, continuing to grow upwards, left at the surface a ring of coral around a lake.

PROBABLE CAUSE OF THE MOVEMENTS OF THE EARTH'S CRUST.—The general opinion is that the slow upheavals and subsidences are consequent on the contraction of the earth by cooling—the warm interior loses heat faster than the comparatively cold exterior, and contracts more than the outer part, which tries to follow the interior but cannot, owing to its curved form, except by bulging up in other places. In this way continents may sink, and the bottom of the sea may be raised above the level of the water.

RELATIVE AGE OF STRATA.

64. Changes the Earth's Surface has Undergone, and in the Forms of Life.—That the surface of the earth is continually undergoing changes is evident from the upheavals and subsidences that are going on continuously, and by the different strata that appear above each other. If we examine the mud and sands of our coasts and seas we find imbedded in or resting upon them relics of many living species of animals and plants. On examining sandstones and clay we find, too, they are associated with organic relics, the beds of coal and peat, &c., revealing the same facts. Hence we come to the conclusion that these deposits or strata are the result of forces tending either to break up and remove, or to deposit and consolidate in new forms. Where dry land is at the present day we have strong evidence that it has been the bottom of the sea at some previous date. The agents causing these changes on the earth's surface are: (1) Aqueous, forming sand and mud banks, &c. (2) Igneous, causing the lavas, &c., issuing from the volcanoes and earthquakes. (3) The works of the polyps in forming reefs, and the chalk-forming animals, *Foraminifera.*

When one stratum rests upon another we come to the conclusion that the *lower* bed was deposited before the *upper* bed was commenced. In this way geologists are able to arrange the strata composing the earth's crust in a series commencing from the oldest, or first formed, up to the newest, or last formed. They are also guided by the fossils appearing in them; for if rocks of the same age or formation are examined we may find some local fossils—yet many are constant—occurring wherever the rocks are found; but in passing to a newer rock there appears a complete change in the fossils, which not only proves it to be of a different formation, but that each age was characterised by its own peculiar *fauna* (animals) and *flora* (flowers), one animal or plant after another disappearing and new species taking their places.

The stratified rocks fall into three great divisions—namely, the Cainozoic, or new; the Mesozoic, or middle; and the Palæozoic, or ancient group. The first division includes the Tertiary and Quartenary, the second (Mesozoic) the Secondary, and the last, Primary, or the oldest strata of which we have any knowledge, each division representing, as nearly as can be determined, a different arrangement of sea and land.

The following table gives the names of the different *formations*, or *systems*, arranged in the order of the superposition, the oldest being at the bottom and the youngest known at the top:—

III.—CAINOZOIC (RECENT LIFE).

Post-tertiary, or Recent Accumulations—Alluvium, fen deposits, river gravels, &c.

Tertiary.—Pliocene—Crag; Miocene—Bovey-beds, &c.; Eocene—Pluvio, Maine series, &c.

II.—MESOZOIC (MIDDLE LIFE).

Cretaceous, or Chalk System—Chalk, greensand, Wealden, &c.

Oolitic, or Jurassic System—Oolite, lias.

Triassic, or Upper New Red Sandstone.

I.—PALÆOZOIC (ANCIENT LIFE).

Permian, or Lower New Red Sandstone—Magnesian limestone series, &c.

Carboniferous System—Coal measures, mountain limestone, &c.

Devonian, or Old Red Sandstone.

Silurian—Cambrian and Laurentian.

In the last (Palæozoic) group of formations the forms of life differ greatly from what are on the earth now, and are still different in the middle division, but not so strange in aspect. In the first, or Cainozoic, we have those that exist at present, the oldest of which is the *Eocene*, containing a few species of shells that now exist; the Miocene still more; the Pliocene, containing the more recent descriptions, though a number of the mammalia that then existed are now extinct.

In the SILURIAN AGE, *trilobites*, a peculiar form of crustacea, abounded, also *graptolites*, &c. The Old Red Sandstone is sometimes called the *age of fishes*, on account of the numerous remains which are found in this system. The fishes were mostly of the *ganoid* type, being cased in bony enamelled plates. Other kinds are the *placoid*, the skin being dotted something similar to the shark, the chief of which were the *asterolepis*, a fish some 20 or 30 feet in length; *holoptychius*, another large fish, with wrinkle-like marks on its scales; *pterichthys*, *cephalaspis*, *osteolepsis*, *coccosteus*, &c.

The CARBONIFEROUS SYSTEM contains coral fossils, such as *syringopora*, *lithostrotion*, &c.; shells, as *spirifera*, and *productus*, *archemediporo*, *euomphalus*, *bellerophon*, *goniatites*, and *nautilus*. Of the coal measures in this system the chief fossils are plants. Among the most important are *stigmaria*, or roots of plants; the *sigillaria*, or the stems; and *lepidodendron*, so called from its scaly bark. The fronds of tree-ferns are numerous, such as *pecopteris* and *neuropteris*, figured kinds; *sphenopteris*, *cyclopteris*, *odontopteris*, &c.

PERMIAN SYSTEM.—The fossils of this formation are not very abundant, but those which appear are associated with a considerable change of species, many species of fauna finally disappearing. Among the chief fossils are *fenestella* (Polyzoa), *productus horridus*, *spirifera alata*, *&c.* (Brachiopoda); *schizodus*, *Bakevellia*, *pecten*, &c. (Conchifera); *Palæoniscus*, *platysomus*, *&c.* (Fishes).

TRIASSIC SYSTEM.—Some of the fossils of this system are *ceratites nodosus*, characteristic of the shells; *estheria minuta* (Crustacea), and *microlestes antiquus*, a little beast of prey, the earliest known mammal, something like a kangaroo. In this system reptiles became more numerous than in any earlier rocks, among which may be mentioned *cheirotherium or labyrinthodon*, *nothosaurus* and *rhyncosaurus*, &c. The *ammonites* and *belemnites* make their first appearance also.

JURASSIC OR OOLITE AND LIAS SYSTEM.—The lias is remarkable for its fossil reptiles. It, together with the oolite, has been called the age of reptiles, from the great development of those animals, both in size and number, of which the genera best known are the *ichthyosaurus*, *plesiosaurus*, and *pterodactylus*. The first of these was a lizard, somewhat like a fish, sometimes more than 25 feet in length; the second had a swan-like neck, and nearly as long as the first; and the last (pterodactylus) had wings, and could fly like a bat. Beetles, crickets, and other insects, have been found in the lias formation; oysters also are abundant. In the oolite *ammonites* and *belemnites* are very abundant, long-legged lizards appearing, and four species of mammals, all pouched animals like the kangaroo, the genera being *amphitherium*, *phascolotherium*, and *stereognathus*.

CRETACEOUS SYSTEM.—The cretaceous fossils, compared with the oolite, are new, not a single species of the latter occurring—the foraminifera now appearing, which resemble very closely those now living in the Atlantic and other seas. The large reptiles, *ichthyo-*

saurus, &c., occur for the last time, in the white chalk, several new genera appearing, as the *mososaurus*. Birds also, about the size of a pigeon, have been found in the upper green sand.

EOCENE SYSTEM (TERTIARY.)—This period—namely, the tertiary—is sometimes called the *age of mammals*, among which may be mentioned *coryphodon*, somewhat like the living tapir, though larger; *hyracotherium*, allied to the hog; *palæotherium*, or ancient beast, about as large as a horse, but like the tapir; *anoplotherium*, with a long powerful tail, and many others. It is supposed that during this system the climate of England was tropical (like that of the East Indies at the present time), on account of the palms, crocodiles, turtles, &c., which have been found; also that this country was joined to the Continent, the proof of which lies in the remains of large mammals making their appearance in different parts of the English deposits in the Eocine time, it being evident that these animals must have *walked* over.

MIOCENE PERIOD.—The plants and flowers of this period closely resemble the flora of the present day, being, among many others, evergreens, oaks, fig-trees, laurels, vines, palms, beeches, and trees of the cinnamon tribe. Among the mammalia there are *dinotherium chœropotamus*, and others which are now extinct; and the elephant, hippopotamus, rhinoceros, giraffe, monkey, deer, &c., which are living species.

PLIOCENE PERIOD.—The remains of the following mammals, among others, have been found in the English beds, or crags, of this period: *Whale, elephant, rhinoceros, tapir, horse, bear, pig, deer, hyena*; and the genera *mastodon* (allied to the elephant, but with very long tusks) and *hipparion* (allied to the horse), both of which are now extinct.

From the crags we learn that a portion of Norfolk and Suffolk were under the sea at the commencement of this period, these formations resembling those deposits now forming in the German Ocean. More than one-fourth of the fossils of the crags belong to extinct species.

POST-TERTIARY OR POST-PLIOCENE, PERIOD.—Remains of animals now inhabiting this country, with others inhabiting other parts of the world, and some altogether extinct, are found in the British formations of this period. Among the mammalia are the *fox, wolf, hyena, reindeer, lion, bison, hippotamus*, two kinds of *elephant, horse, pig, rabbit, squirrel, &c.* We also meet with proof of man's existence at this age by the discovery of some of his works, such as flint knives, hatchets, arrow heads, &c. In Continental gravels and caves of this age, man's bones have been found side by side with those of the mammoth and other extinct animals.

Glacial Period.—In this period refrigeration, which had been growing more and more since the Pliocene times, attained its maximum. The climate of our own country must have been similar to such as we now find in the frozen regions, such as Greenland. Evidences tending to prove this may be found in traces of ice-action, such as the polishing of rocks by glaciers, *roches-mountonnées*, and perched blocks—hills and mountains rounded in form—especially in the Highlands of Scotland and Wales, the *boulder clay* or "fell" being the morainic matter resulting from the abrasion of the rocks over which the ice moved.

During this period the *Glacial Drift* was formed. This marine formation contains many grooved and striated stones, the whole appearing to be morainic matter of the glaciers which covered the islands formed by the high parts of Scotland, Cumberland, and Wales. The whole of the North of Europe appears to have been gradually submerged at this period; blocks of stone appear to have been carried on icebergs from Norway and Sweden to our country, and scattered about.

The partial depression of the British area was succeeded after a long time by a slow movement of elevation. This continued more or less until within recent times. After emerging from the sea, the climate appears to have gradually grown milder; the glaciers gradually declined in size until they disappeared entirely. At what date this period occurred we are not able to speak definitely, but according to Dr. Croll it occurred about 210,000 years ago, at a time when the earth's distance from the sun in winter was more than ten and a half million miles greater than it is at present, and the northern hemisphere turned away from the sun at the same time.

65. The Age of the Earth is not yet, and doubtless never will be, known, but many conjectures and calculations have been made regarding it, the chief of which are based on calculations made upon the heat of the earth, and the time it would take to cool from its molten state. From experiments made upon the cooling of lava and certain other rocks by Bischof, Professor Helmholtz concludes that the earth could not cool from the temperature of 2,000° C. to 200° C. in less than 350,000,000 years, and scores of millions more must have elapsed to have reduced it to 94° C.—the highest heat at which it is estimated that animal and vegetable life could commence. Sir W. Thompson is of opinion that the solidification of the crust took place about 100,000,000 years ago, bringing the probable age of the earth to 500,000,000 years. Other evidence regarding the antiquity of the globe is drawn from the effects of rivers in their action on the earth's crust. For example, it is well-known that the *Falls of*

Niagara are now seven miles nearer Lake Erie than they have been at some previous date; and taking six inches at the calculated rate of retrocession per annum it gives 186,000 years as the time required for the river to have performed this work.

PHYSICAL GEOGRAPHY.

THE SURFACE OF THE EARTH—DEFINITIONS.

MATHEMATICAL DIVISIONS OF THE EARTH.

The **Axis of the Earth** is an imaginary line passing through its centre, and round which it rotates daily.

The **North and South Poles** are the extreme points of its axis.

The **Equator** is a great circle passing round the middle of the earth at equal distances from the poles, dividing it into two equal portions, the northern half being called the *Northern Hemisphere*, and the southern half the *Southern Hemisphere*.

A **Hemisphere** is one-half of a sphere. Hence, considering the earth as as a sphere, it means one-half of it.

The **Meridians** are great circles passing round the earth at right angles to the equator, and cutting each other at the poles.

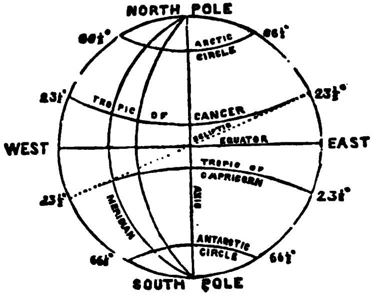

Fig 7

Latitude is the distance of a place north or south of the equator.

Longitude is the distance east or west of any given meridian. Longitude is reckoned in this country from the meridian of Greenwich, which is called the *first* meridian.

The **Tropics** are two circles drawn parallel to the equator, namely, the Tropic of Cancer, about 23½° north of the equator, and the Tropic of Capricorn, about 23½° south of the equator.

The **Polar Circles** are two lines drawn round the earth parallel to the equator, namely, the Arctic Circle, nearly 23½° from the north pole, and the Antarctic Circle, nearly 23½° from the south pole.

The ECLIPTIC is a great circle cutting the equator at an angle of 23½° at two opposite points, reaching the tropics as its extreme limit, north and south. It represents the sun's apparent path in the heavens, but in reality the path of the earth round the sun.

The points where the ecliptic cuts the equator are called the *Equinoctial Points* or *Nodes*, because, when the sun is in these parts of his course, the day and night are equal. These equinoxes take place twice a year, namely, on the 21st of March, and 21st of September.

The ZONES are *five great belts* into which the earth is divided by the tropics and polar circles. (1) The *Torrid Zone*, between the tropics, so called on account of its great heat, through the sun being always vertical in some part of that space. (2) The spaces between the tropics and the arctic and antarctic circles on either side, are called *Temperate Zones* (north and south), having a milder or *temperate* climate. (3) The spaces between the polar circles and the poles are called *Frigid Zones*, from their extreme cold. The breadth of each of the torrid zones is about 1622·5 miles; of each temperate, about 2969 miles; and of each frigid, 1622·5 miles. Hence, calculating their respective areas, we have—

	Sq. miles.	Parts	
North Frigid Zone	8,182,797	Or 4	Out of 100, nearly.
North Temperate Zone	51.041,592	26	
Torrid Zone	78,814,115	40	
South Temperate Zone	51,041,592	26	
South Frigid Zone	8,182,797	4	
Total	196,662,898	100	

NATURAL DIVISIONS OF THE SURFACE OF THE EARTH.

A CONTINENT is a large continuous extent of land, including several countries, as Europe, Asia, &c.

An ISLAND is a smaller extend of land, and entirely surrounded by water, as GREAT BRITAIN, IRELAND, SICILY.

An ARCHIPELAGO consists of several clusters or groups of islands. This name was originally applied to the Gulf of the Mediterranean, between Greece and Asia.

A PENINSULA is land almost surrounded by water, as *England*, *Italy*.

A CAPE is a head or point of land stretching out into the water, as Cape of Good Hope. Other names of Capes are, *Promontory*, *Head*, *Headland*, *Point*, *Naze*, *Ness*.

An ISTHMUS is a narrow neck of land uniting two larger portions together, as the Isthmus of Panama, between North and South America.

A **COAST** or **SHORE** is the part of a country bordering on a sea, lake, or river.

A **MOUNTAIN** is a portion of the land raised considerably above the surrounding portion, as *Mont Blanc*, *Snowdon*. When under 2,000 feet above the level of the sea, they are termed hills, as *Cotswold Hills*, *Malvern Hills*. When they form a continuous line they are called chains, or ranges, a series of which are termed a *system*.

A **VOLCANO** is a mountain which casts forth smoke, flame, lava, ashes, &c., as *Vesuvius*, in Italy.

A **VALLEY** is a hollow, or lowland, lying between mountains and hills ; when very narrow at the bottom, with steep sides, it is called a *ravine*.

A **PLAIN** is a portion of country nearly flat, or level, and not raised much above the level of the sea. When a tract of this description lies high, it is called a *plateau* or *tableland*. A series of plains at different levels are called *terraces*.

Plains have received specific names in different parts of the world, derived from the languages of the people. Thus, in North America they are called *savannas* or *prairies* (meadows) ; *pampas*, *llanos*, and *selvas*, in South America ; *steppes*, in the south-east of Europe and the north-west of Asia. *Landes* is the name given to extensive marshy or sandy tracts, covered with heath, on the coast of the Bay of Biscay.

A **DESERT** is a barren tract of country, usually consisting of sand and rocks, as the *Sahara Desert*. A fertile spot in the midst of a desert country, caused by the presence of water, is called an *oasis*.

The **OCEAN** is the continuous mass of salt water which surrounds the globe, particular parts receiving particular names, as the *Pacific Ocean* (peaceable).

A **SEA** is a smaller body of salt water nearly surrounded by land, as the *Mediterranean* and *Baltic Seas*.

A **GULF** is a portion of the sea running into the land and having a narrow opening, as the *Gulf of Mexico*.

A **BAY** is a portion of the sea running into the land, having a wider opening than a gulf, as the *Bay of Bengal*.

A **CREEK** is a small inlet on a low coast. In Australia and America it means a small inland river.

A **CHANNEL** is a body of water uniting two larger bodies of water. When it is narrow it is called a *strait* or *sound*.

A **LAKE** is generally fresh water surrounded by land, as *Lake Superior;* but some are salt, and when large are called seas, as the *Caspian Sea*.

A **LAGOON** is a shallow lake formed on low lands by the overflowing of rivers or seas.

A **RIVER** is a stream of fresh water rising in the land, draining a portion of the country, and flowing into the sea, a lake, or another river. A small stream is termed a *rivulet* or *brook*. A river that falls into another is called a *tributary*, and where they meet the *confluence;* the place where the river rises its *source*, and where it empties itself into the sea its *mouth*, but when very wide it is termed an *estuary*, *firth*, or *fiord*. The channel which contains its waters is the *bed* and the sides its *banks*.

The BASIN of a river is that portion of country drained by the river and its tributaries. All the basins inclined to any particular sea are called a *river system*.

A WATERPARTING is the elevated land which separates one river basin from another.

A DELTA is a tract of alluvial land deposited at the mouths of certain rivers, dividing them into two or more streams, so called from its resemblance to the Greek letter Δ, named *delta*.

EXTENT AND DISTRIBUTION OF LAND AND WATER.

66. **Land and Water** are distributed very unequally, as only a little more than one-fourth is land, the remaining part, nearly three-fourths, being water; or, more exactly, out of 197 millions of square miles 51½ are land and 145½ water—that is about 26·2 per cent land and 73·8 per cent water, its general distribution being as follows:—

Northern Hemisphere ...	Land,	38½	million square miles.
	Water,	60	
Southern Hemisphere ...	Land,	13	
	Water,	85½	
Total.....................		197	

Of the land there is about three times as much in the Northern Hemisphere as there is in the Southern, and in the Eastern about two-and-a-half times that in the Western. Regarding the distribution in the zones it may be stated that in the North Frigid Zone about *one-third* is land, in the North Temperate about one-half, in the Torrid Zone one-half, and in the South Temperate one-tenth.

Dividing the globe into two hemispheres, one having London* for its centre, and the other New Zealand, the former will embrace $\frac{16}{17}$ of the whole land, and the latter only $\frac{1}{17}$ land, or nearly all water. This fact may account for the prosperity of London, being placed as it were in the very centre of the nations.

67. **Divisions of the Water.**—There is but one ocean really, but for the sake of convenience it is divided into five different parts, or basins, namely—

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* The exact spot lies in the George's Channel, near the middle.

The **Atlantic Ocean**, between the western coasts of the Old World and the eastern coasts of the New.

The **Pacific Ocean**, between the eastern coasts of the Old World and the western coasts of the New.

The **Indian Ocean**, south of Asia and east of Africa.

The **Arctic Ocean**, lying round the North Pole.

The **Antarctic Ocean**, lying round the South Pole.

The areas of these divisions are roughly estimated as follows :—

	Greatest Length. Miles.	Greatest Breadth. Miles.	Areas. Square Miles.
Pacific Ocean	9,000	12,000	72,000,000
Atlantic Ocean	9,000	4,100	35,000,000
Indian Ocean	4,500	4,500	25,000,000
Arctic Ocean	3,240	2,500	5,000,000
Antarctic Ocean	3,266	3,266	5,000,000

68. Area and Distribution of the Land.—As before stated, there are about 51½ million square miles of *land* out of the total 197 million square miles area of the earth. Dividing the land into four divisions—namely, Europe, Asia (with Polynesia), and Africa, in the Eastern Hemisphere, commonly known as the Old World, and America (North and South), known as the New World—the respective areas are as follow :—

OLD WORLD, INCLUDING ISLANDS.	Square Miles.	Relative Size.
Europe	3,500,000	1
Asia, with Polynesia	21,500,000	6
Africa	12,000,000	$3\frac{3}{7}$
NEW WORLD, INCLUDING ISLANDS.		
North America	7,500,000	$2\frac{1}{7}$
South America	7,000,000	2

Taking Australia by itself it contains about 3½ million square miles, and the islands surrounding about 1 million ; so that Oceania contains 4½ millions of square miles. It is calculated that the area of all the islands on the globe (not including Australia) is between 2½ and 3 millions of square miles.

Islands are divided generally into three classes : (1) *Continental*, or seaward extensions of the continent upon whose coast they lie, as the British Isles, for instance, which evidently belong to the same formation as the continent of Europe, and have, at some period, been attached to it, proofs of which are shown in the fossils of animals belonging to Europe having been found in this country ; and the only way to account for their presence here is that they must have walked over ; but since that time the land on which the German Ocean now stands has sunk to a depth of—in the deepest part—50 fathoms, so that an elevation equal to that would again connect them. (2) *Volcanic islands*, which are generally of a different structure to the continent near them. The chief of this class are the Sandwich Islands, Marquesas and Society Islands, in the Pacific, Iceland, Jan Mayzen Island, the Azores, the Canaries, Cape de Verdes, St. Helena, Ascension, Trinidad, &c. (See "Volcanoes," 53 and 54.) (3) *Coral islands*, or those formed by the coral polyps. (See "Organically-formed Rocks," 47 and 56.) The chief of these occur in Polynesia, the West Indies, the Red Sea, the Indian Ocean, and the Atlantic Ocean. The largest barrier-reef, off the north-east of Australia, is more than 1,000 miles in length.

Among the largest of the islands may be mentioned Greenland, containing 380,000 square miles; Borneo, 280,000; New Guinea, 274,500; Madagasgar, 234,000; Sumatra, 177,000; Niphon, 109,000; and Great Britain, 83,830.

69. Configuration (Shape) of the Land.—Regarding the general aspect of the surface of the land there are two things to be considered—(1) Its horizontal outline, giving us the *contour;* and (2) its vertical outline, or *profile*. Considering the horizontal outline of the different masses, they present many points of resemblance and certain points of contrast.

(*a*) Though the greater bulk of land lies in the Northern Hemisphere, the greatest extension of the Old World is from east to west, while that in the New is from north to south. Hence the latter is subject to a greater diversity of temperature, and also of vegetable and animal life, owing to its crossing the different zones—frigid, temperate, and torrid.

(*b*) Both masses in the Old and the New World attain their greatest dimensions from east to west, along the same parallel of latitude, namely, that of 50° north, which places much of North America, Europe, and Asia within the temperate zone, while only the narrower portions of South America, Africa, and the East India Islands lie under the intense heat of the equator.

(*c*) Both the Old and New Worlds present a broad base towards the north, terminating along the parallel of 72°, and taper towards the south, terminating in far separated promontories. The direction of the chief peninsulas in both worlds (Old and New) is towards the south, these peninsulas being, in many cases, accompanied by an outlying island or islands, as South America by Tierra del Fuego and the Falkland Islands, Africa by Madagascar, Hindostan by Ceylon, and Australia by Tasmania. It may also be noticed at the same time that these promontories terminate in abrupt rocky precipices, which are often the termination of a mountain range.

(*d*) In each hemisphere (Western and Eastern) a large portion is nearly entirely separated from the principal mass, Africa being nearly separated from the Old World, and the severance of Australia from Asia; while in the New, South America is very nearly separated from North America.

(*e*) The general disposition of the continents and larger islands is in the direction of their principal mountain axes, or mountain ranges. The tendency of islands is generally to arrange themselves in groups, or archipelagos.

(*f*) The extremities of each continent (Old and New World), north and south, are nearly in the same meridian—the north-west point of Greenland being nearly in the same meridian with Cape Horn, North Cape with the Cape of Good Hope, &c.

70. Coast-lines.—The shape of the coast-lines presents also some peculiar features on opposite sides of the same ocean, projections or protuberances on one side corresponding with recesses on the other. This may be noticed very strikingly with regard to the Atlantic, where the recesses in the New World seem made for the protuberances of the Old to fit exactly in.

The extent of the coast-line is one of the most important features in Physical Geography, as on it depends greater diversity of climate and productions, and the facilities for navigation and commerce, from which nations derive their wealth, power, and independence. This may be regarded as the chief cause of the greatness of Europe and North America, as they have the greatest relative extent of coast-line. Africa on the contrary, has the least relative coast-line, and is the most uncivilised, the country being in a great degree shut out from the influence and enterprise of commerce, and the benefits resulting therefrom. The following table shows the relative extent of coast-line of the different continents:—

	Sq. miles.	Length of coast.	Sq. miles for one of coast.
Europe	3,500,000	20,000	170
Asia	17,500,000	33,000	533
Africa	12,000,000	16,500	680
North America	7,500,000	28,000	260
South America	7,000,000	16,500	420
Australia	3,500,000	7,600	460

From the above it will be seen that Europe has one mile of coast for every 170 square miles of surface, and North America one mile for every 260 square miles of surface, but Africa only one mile for every 680 square miles of surface. It has hardly an inlet where a ship can harbour in round the entire coast, but in Europe there are gulfs, inland seas, and peninsulas, the latter being in places again divided into inlets, &c.

71. Vertical Outline.—The surface of the land is very varied, assuming many forms and elevations. In all the continents there is a gradual rise from the seashore towards certain points or ridges in the interior, which form the great *water-partings* of their respective continents. (There are one or two exceptions to this rule, namely, the region surrounding the Caspian Sea, Dead Sea, and Lake Ural.) This ridge of greatest elevation is placed more towards one side than the other, so that there are two slopes of unequal length, the long side, which is generally four or five times the length of the other, forming the *slope*, and the shorter the *counter-slope*. The long slopes in the Old World are turned towards the north, and the short ones towards the south. But in the New World the *long* (*or gentle*) slope is turned towards the east, and the *short* (*or rapid*) one towards the west.

According to Hughes, the lengths of the longer and shorter slopes are:—

	North Slope.	South Slope.
Eastern Asia	2,600	400
Western Asia	900	80
Central Europe	450	100
Africa	3,300	600
	East Slope.	West Slope.
North America	1,600	800
Central America	2,000	300
South America	1,850	50

In all continents *the elevations increase from the poles to the tropics; and also extend in the line of the greatest length of the continents*. Thus the highest point in the Old World—namely, Mount Everest—is situated near the Tropic of Cancer, and that in the New World (Aconcagua, in Chili) is not far south of the Tropic of Capricorn. The effect of this law is to temper the fierceness of the heat of the tropics, giving them a variety of climate.

MEAN ELEVATION.—The mean elevation of a continent is *the height above the sea level that it would be if all the hills and mountains were levelled, filling all the valleys up, so that the whole should have an even surface*. It has been estimated that the mean elevation of Europe would be 670 feet; of Asia, 1,132 feet; of Africa, 910 feet; of North America, 750 feet; of South America, 1,150 feet.

MOUNTAINS.

72. Respecting the Origin of Mountains we again call in *heat* to our aid. There is no doubt that the vast stores of this force existing in the interior of the earth are continually at work effecting alterations in the surface. In giving this off, as we have stated before, the warm interior loses heat faster than the comparatively cold exterior, and contracts more than the outer part. This tries to follow, but is unable to do so owing to its curved form, except by bulging up in other places. Professor Ramsey, in his excellent work on Physical Geography and Geology of Great Britain, asks, by what means were masses of strata, many thousands of feet thick, bent and contorted, and often raised high into the air, so as to produce existing scenic results by affording matter for the elements to work upon? Not by igneous pressure from below raising the rocks, for that would stretch instead of crumpling strata in the manner we find them in the Alps, Norway, and the Highlands, or, in less degree, in Wales and Cumberland; but rather because of the radiation from the earth of heat into space, gradually producing a shrinkage of the earth's crust, which here and there giving way, becomes crumpled upon lines more or less irregular, producing partial upheavals, even though the absolute bulk of the globe was diminished by cooling. Professor Geikie also attributes it to the same cause. Thus he says in his work on Geology, "As a consequence of the slow cooling of our planet its outer crust, under the enormous trains of contraction, has been forced into ridges in different places with wide sunk spaces between. The ridges form mountain chains, while the sunk spaces are filled with the waters of the ocean."

Sir C. Lyell also furnishes evidence which seems to confirm this opinion. He tells us in his Elements of Geology that "the parallel ranges of the Alleghany mountains consist of strata folded into a succession of convex or concave flexures."

The minor elevations, which we term Hills, appear in most cases at least to owe their form to the process of denudation. (See action of rain, springs, &c., on the earth's crust.)

73. It is seldom that a mountain occurs singly. They appear mostly in *ranges* or *chains*. There are a few instances where they do, owing their origin chiefly to volcanic energy, among which may be mentioned Mount Egmont in New Zealand, and the Peak of Teneriffe in the Canary Islands. The chains or ranges generally consist of parallel ridges, the centre one being the highest. they have generally their highest elevation near the middle, gradually drooping down into the plain towards their extremities. The lateral ridges which break off from these may again, in their turn, send off smaller ridges or spurs in numerous ramifications. Several chains constitute what is called a *group*, and several groups a *system*.

The outlines of mountains depend chiefly on the geological structure, and partly on the amount of waste and degradation to which they have been subjected. In this manner, hills that are composed of hard basalts and greenstones, alternating with soft tufas or stratified rocks, assume *tenaciform* declivities; and extinct volcanic hills put on a *crateriform* aspect. Those chiefly composed of hard massive strata—as limestone, conglomerates, and sandstone—present a tabular appearance; and mountains capped and flanked by crystalline schists and quartz are *serrated* with peaks and pinnacles.

The mountain chains often traverse immense regions, forming the boundaries of great nations living round their base. For instance, the Andes, continued by the Mexican and Rocky Mountains, extend through all the different zones and climates of the world.

74. Mountain Systems.—There are really only two *great mountain systems* in the world. (1) That in the New World is a continuity of a vast and extremely precipitous line of very elevated mountains running parallel with the west coast of America, and from the Arctic Ocean almost to the extremity of Patagonia—a distance of nearly 9,000 miles. Throughout the whole of this border we notice a distinct and unmistakable tendency to a system of double or triple ridges, nearly or exactly parallel, extending for hundreds of miles in succession, and resumed again and again when interrupted. (2) In the Old World there is a broad belt of mountainous country running through the land in a general direction from the East Cape, in Siberia, west-south-west across Asia to Spain and Morocco, being a distance of between 8,000 and 9,000 miles. All mountain chains, with the exception of the African and Australian ranges, are offshoots of one or the other of these two systems.

For the sake of reference the mountains have been arranged in various systems. Thus, those of EUROPE are arranged into the *Britannic*, *Iberian* (or *Spanish*), *Alpine*, *Carpathians*, *Scandinavian*, *Uralian* systems, &c. Those of ASIA into the *Taurus*, *Kuen-lun*, *Thian-shan*, *Altai*, *Himalayas*, &c. AFRICA, into the *Atlas*, *Abyssinian*, *Eastern*, *Western*, or *Guinea*, &c. While those of the NEW WORLD are the *Rocky Mountains*, the *Mexican Andes*, and the *Cordillera of the Andes*.

75. Europe.—The *Britannic System* consists of a number of detached chains, as the Grampians, Cheviots, Cumbrian, Hibernian, and Welsh mountains; they are sometimes said to form the southern continuation of the Scandinavian system. The highest mountains are Ben Nevis, 4,406 feet, in Inverness-shire, and Cairntoul, in Aberdeenshire, 4,285 feet; the highest in England and Wales is Snowdon, 3,590 feet; and in Ireland, Carn-Tual, 3,412 feet high.

The *Spanish System* embraces several detached mountain chains, including the *Pyrenees*, the *Cantabrian Mountains*, the *Sierra Nevada*, the *Sierra Morena*, and the sierras of the central tableland. The reason of their being called *sierras* is on account of their jagged and sawlike appearance. The name comes from a Spanish word meaning a saw. The principal chain is the Sierra Nevada, ranging from east to west, the highest point is Mulhaçen, 11,678 feet, and Maladetta, in the Pyrenees, 11,168 feet. The Sierra Morena runs parallel with the Nevada chain, but lies farther north. There are several minor chains lying between the Pyrenees and the Sierra Nevada.

The *French System* includes all the hilly eminences in France lying to the north of the Garonne, west of the Rhone and south of the Rhine. The chief detached mountains are the Auvergne Mountains, which are a group of extinct volcanoes, the highest peak of which is Plomb de Cantal, 6,113 feet.

The *Alpine System* embraces the whole of those extensive and lofty mountains which, from Switzerland as a centre, spread in ranges more or less persistent, which confer on Southern Europe one of its chief and peculiar features. It may also be said to form the backbone of the continent. These ranges have many minor divisions, as the Maritime, Cottian, Graian, Pennine, Bernese, Carnic, Noric, and other Alps, which extend in a north-east direction from the shores of the Mediterranean to the tableland of Bohemia; the Apennines, traversing the entire length of Italy, and terminating in the volcano Etna, in Sicily; the Slavo-Hellenic ranges, lying between the shores of the Adriatic and the plains of the Danube; and the Balkan group, in Turkey, ranging from east to west. The highest point in this system is Mont Blanc, 15,744 feet. The other chief heights are Mont Pelvoux, 14,108 feet; Etna, in the Apennines, 10,874 feet; Tehan-Dagh, 9,700 feet, in the Balkan mountains; Olympus, 9,749 feet, in the Hellenic range.

The *Carpathian System* includes all the mountains and eminences situated between the Rhine, Dneiper, and Danube, the plains of Northern Germany and Western Poland. The western portion of the Carpathian chain, near the mouth of the Danube, is called the Transylvanian range. The highest point in this range is Ruska Joyana, 9,912 feet, in the Eastern Carpathians. In the main range there are several high peaks grouped upon one very large mountain, Tatra, the highest point being 8,524 feet; the Csalic Peak, 8,314 feet; and the Lomnitz to more than 8,000 feet.

The *Scandinavian System* embraces the whole of the mountains and highlands of Norway and Sweden, extending in a north-eastern direction from the Naze to the North Cape—a distance of nearly

1,000 miles. They consist of the Novrska Fjellen (Norwegian range) and the Kjölen. The latter lies to the north, being about 500 miles in length, but not so generally elevated as the former, though it rises to about 6,200 feet in Sulitelma. The former is about 400 miles long, lying to the south, and containing the highest points in the group, viz., Sneehatten, in the Dovrefeld (in the middle), about 8,000 feet; though in the southern range Skegstol-tend is said to be 8,670 feet.

The *Ural System* or chain forms the boundary line between Europe and Asia, embracing the Ural Mountains and forming the waterparting between the extensive basins of the Volga and Obi. This range runs in a true meridianal direction for a distance of more than 1,600 miles, and consists of round-backed, plateau-shaped masses, of very moderate height, in most places not exceeding 2,000 feet, though there are one or two points a little over 5,000 feet, viz., Koujak-Ofski, 5,397 feet, and Obdorsk, 5,286 feet.

76. **Asia.**—The *Altai*, the great mountain system of the Old World, commences on the shores of Behring Strait, at the East Cape, ranging for some distance to the west. Afterwards it bends toward the south, branching into Kamtschatka. The chief range bends again to the west, running through Siberia, when it is called the *Aldan* Mountains, still continuing westward along the 50th parallel of latitude, passing Lake Baikal, and reaching the 84th degree of longitude. The breadth of this range in many places exceeds 800 miles, but the height is not so great in comparison to its length and breadth. The highest point is Bielukha, 12,796 feet. Partly parallel to the Altai range are three ranges, viz., (1) *Thian-shan*, (2) *Kuen-lun*, and (3) the *Great Himalaya* range. The first two run eastward, Thian-shan near to the 42nd parallel of latitude, and Kuen-lun near to the 36th, into China. The last named forms the southern boundary of the desert of *Gobi*, Thian-shan lying to the north of that desert. The highest point in the Thian-shan is Khan-Tengri, 21,000 feet. In the Kuen-lun some points reach the height of 22,000 feet. In these chains are active volcanoes, some as far as 1,500 miles from the sea. The last of these three ranges—namely, the Great Himalaya—extends about 1,500 miles along the southern border of the central plateau, separating Thibet from Hindostan. The highest point is Mount Everest, reaching 29,002 feet, or more than 5½ miles in height, being the highest peak in the world. There are several other very high summits in the central portion, attaining in several places the height of about 25,000 feet, and between 30 and 40 more than 23,000 feet. Kinchingunga reaches 28,156 feet, and Dhawalagiri 26,826 feet. The passes of the Himalaya are from 10,000 to 17,000 feet high. It has been noted that vegetation ascends higher on the north side than on the south side. This singular fact is supposed to arise from the reflection of the sun's rays.

The *Hindoo Cooch* (or *Koosh*) traverse the north of Afghanistan and Persia. They may be regarded as prolongations of the Himalaya. The highest peak exceeds 20,000 feet. The *Taurus* and *Anti-Taurus* ranges, which encircle the tableland of Asiatic Turkey, the highest point of which is Mount Argish (or Argous) in Armenia, 13,197 feet. In connection with the Taurus may be mentioned the Lebanon range, which attains a height of 10,050 feet in Dahr-el-Khotib; Hermon, 9,376 feet; and Sinai and Horeb, 7,413 and 8,593 feet respectively.

The *Caucasian* includes the mountains of Elburz and those between the Caspian and Black Seas, whose highest points are Demavend, 21,500 feet; Elburz, 18,493; Koschtantan, 17,096; Dychtan, 16,925; and several others exceed 16,000 feet in height. There are several smaller ranges that have not been noticed, the chief of which are the Armenian Mountains, ranging between Turkey and Persia, the highest peak being Mount Ararat, 17,112 feet.

77. **Africa.**—In the extreme north we have the *Atlas System*—between the Mediterranean seaboard and the Sahara—extending from Tripoli on the east, to the Atlantic on the west, namely, to Cape Geer. Geologically, it is connected with the systems of Southern Europe, and consists of three or four parallel ranges, gradually increasing in height from east to west. At Tripoli it is only about 2,000 feet above the level of the sea, in Tunis it is 4,500 feet, in Algeria 7,700, while in Morocco it rises to the height of 11,400 (Mount Miltsin or Atlas) and Jebel Tedla to 13,000 feet. Several smaller ranges proceed from the main range—one branch travelling north and terminating in Cape Spartel, at the Strait of Gibraltar.

The next system of importance is the *Abyssinian*, which is connected with and forms the lofty tableland of Amhara, the height of which is 8,000 feet above the level of the sea. The two principal chains—namely, Samen and Taranta—range in a northerly direction, between the upper forks of the Nile and the Red Sea, and run along the latter's shores as far as the lower hills of Egypt. In the Samen, or upper range, we have the highest points, namely, Ras Detchen, 15,986 feet; Buahat, 15,000 feet; Abba Jaret, 14,707 feet. In the Taranta, or lower range, the heights descend gradually from 9,000 to 5,000 feet, towards the Red Sea and Plains of Egypt. This system consists chiefly of granites, porphyries, syenites, and crystalline schists.

The *Guinea System* usually embraces the Kong and Cameroon Mountains. The Kong, between the Gulf of Guinea and the Niger, generally average from 1,000 to 3,000 feet; and the latter, on the west, stretching eastward, rise to above 13,000 feet in height. The hills of Cape Colony form a series of sandstone plateaux, or *karoos*,

rising from Table Mountain, 3,816 feet, to the summits of Nieuvelt and Snieuvelt Mountains, in the north of the colony, which in some cases reach 10,000 feet, as in the Compass Bay, in the Sneeuwveld or Snowy Range. This system of mountains is sometimes termed the Cape System.

Polynesian System.—Not much is at present known of the mountain chains of Australia. The highest points in this country are Mount Kosciusko, 6,500 feet, and Sea View, 6,000 feet. These are in the chain which extends along the eastern coast, from Torres Strait on the north, to the extreme point of Tasmania on the south. The highest points in Polynesia are the active volcanoes of Manna Kea and Manna Loa, in Hawaii, each about 14,000 feet, though in New Zealand there are some points reaching from 10,000 to 12,000 feet.

The highest mountains of the Old World are formed of granite; and gneiss and mica-slate also form large mountain masses.

NEW WORLD, OR AMERICAN SYSTEMS.

78. South America.—The mountain chains of South America may be ranged into two systems. (1) The *Cordillera of the Andes*, and (2) The *Mountains of Brazil*. The Andes extend along the western coast, from the Magellan Straits to the Caribbean Sea, in two or three parallel chains, a distance of nearly 4,500 miles, and varying in breadth from 40 to 340 miles. They may be termed the largest mountains in the world, being so lofty throughout, and differing from the Himalaya by rising from the sea. The highest points are in the Bolivian Andes, reaching in many places from 13,000 to over 21,000 feet. In Chili many summits exceed 16,000 feet; the highest peak of the range—namely, Aconcagua—being 22,300 feet. Chimborazo is 21,424 feet. In Patagonia they do not exceed much above 6,000 feet. This system (Andes) forms one of the grandest centres of volcanoes in the world, most of its highest peaks being volcanic—Aconcagua, for instance, the highest of the range.

79. North and Central America.—The *Andes* also form the chief system of Central and North America, though known by a different name than in the South. Continuing from the Isthmus of Panama to the North of Mexico they are called Central Andes. The greater part of Mexico consists of magnificent tablelands, from 5,000 to 8,000 feet high. The highest peak is Popocatapetl, 17,720 feet. In North America the system is termed the Rocky Mountains, which consist chiefly of two parallel ranges, running generally in the direction of the Pacific to the Arctic Ocean, a distance of more than 5,000 miles, so that the Andes extend a total distance of nearly 10,000 miles, and in places they are 1,000 miles in breadth. The highest peaks of the Rocky Mountains are Mount Brown, 16,000 feet, Mount Hooker, 15,000 feet, and Mount Murchison, 15,000 feet. The summits of the Andes are formed of porphyry and basalt (igneous rocks). In the maritime or western range the highest peak of North America is to be found, namely, Mount St. Elias, on the coast, in latitude 61°, reaching a height of 17,800 feet. On the east are the Alleghanies, or Appalachian Mountains, extending for about 1,200 miles in length, the highest point of which is Mount Washington, 6,634 feet.

TABLELANDS, OR PLATEAUX.

80. **Tablelands** are extensive upland plains, consisting of very large areas of surface, high above the level of the sea, and varied by hill and dale, lake and river. Few mountains have their bases at or near the sea level, but mostly rise on these tablelands. It is from these tablelands that many of our noblest rivers have their sources. The chief tablelands are—

Asia.—It is in this continent that we have the grandest examples of tablelands and plateaux, both in extent and elevation, occupying two-fifths of the entire continent, stretching from the Mediterranean to the Pacific, being 6,000 miles in length, 2,000 miles broad at the eastern extremity, 700 to 1,000 in the middle, but narrower towards the Mediterranean. We may divide these plateaux into two great divisions, namely, (1) The Central Asia or Eastern Plateaux ; (2) The Western Plateaux, joined to the Eastern by the Hindoo Cooch. In the Central Plateaux lie the vast deserts of Gobi, Scha-mo, and Hanai (Dry Sea). The rainless desert of Gobi covers an area of 400,000 square miles, rising from 4,000 to 6,000 feet in height. To the south of these lie the plateaux of Thibet, the loftiest inhabited portion of the globe, having an elevation (between the Kuen-lun and the Himalaya) of 15,000 feet, and reaching in some points 17,000 feet, with an area of 166,000 square miles To the south-west of the Central Plateaux lie the great tablelands of Persia, or Iran, rising from 2,300 to 3,500 feet above the sea level, and with an area of 300,000 square miles, presenting a riverless and desolate region. In succession to this plateaux extend the tablelands of Arabia and the Great Desert of Sahara, in Africa. The entire sandy and arid tablelands of Asia—namely those of the central and western plateaux—extend over 120° of longitude and 17° of latitude, or an area of 5,000,000 square miles Not belonging to either of the above divisions are the plateaux of Armenia, north-east of Turkey in Asia, 7,000 feet high, and the Deccan, in the Indian Peninsula, rising from 1,600 to 2,000 feet in Hyderabad, and 4,000 feet and upwards in Mysore.

Europe.—The plateaux of this country are very few, and of little importance. The highest are those of Spain, ranging from 2,000 to 3,000 feet above the sea, and extending into Portugal, covering an area of 100,000 square miles. The central part is edged or fringed by mountains on all sides, and the ranges of the Sierras Nevada, Morena, &c., rise out of it. The largest plateau in extent lies in the east of Europe, separating the low plains of Northern and Central Russia; its area is more than 150,000 square miles. To the south of this plateau lies the Carpathian, but not near so large.

Africa.—Not much is known of the tablelands of Africa; but some elevated tracts occur in Abyssinia, extending southwards to the extremity of the continent. The great lakes, *Albert Nyanza* and *Victoria Nyanza*, are situated on this tableland. Some parts of Africa lie really below the sea level.

North and South America.—In Mexico, or Central America, we find the greatest unbroken extent of tableland known, extending, north and south, a distance of 1,600 miles, and a breadth of 360 miles, or more. The surface is a dead level, with the exception of where volcanic cones rise up, and ranges from 4,000 to 7,000 feet in height.

In *North America* the chief plateau is called the *Great Basin*, lying between the ranges of the Sierra Nevada and the Rocky Mountains, and extending from Mexico to the Arctic Sea, about 2,000 miles, its greatest breadth being 600 miles, and mean height 5,000 feet. Another tableland, but not so large, stretches from Hudson Strait, in Labrador, to the north of Alhambra, its greatest height not exceeding 2,000 feet. In *South America* the principal one is Desaguadero, lying high up among the tops of the Andes, attaining in Bolivia a height of 13,000 feet, its length being about 500 miles, and breadth from 30 to 60 miles. It is on this plain that Lake Titicaca stands, at an elevation of 13,000 feet, being one of the most elevated sheets of water. The Plateau of Quito is 200 miles long and 30 wide. The city of Quito is situated at the height of 9,540 feet, having a view of eleven snow-clad mountains (*nevadoes*). The only other plateau worthy of note is the Plateau of Brazil, the area of which is about 1,500,000 square miles, and the mean height about 3,000 feet.

The following table gives a few of the most elevated tablelands, compiled principally by Humboldt:—

	Feet.
Bavaria, Germany	1,660
Castille, Spain	2,240
Plateau of Switzerland	2,000
Victoria Nyanza, East Africa	3,300
Iran, Persia	4,500

	Feet.
Armenia, South of the Black Sea	7,000
Mexico, Central America	7,483
Quito, Andes	9,600
Bolivia, Andes	12,900
Thibet 10,000 to	15,000
Desaguadero, Andes	13,000
Ravanabradu, East Asia	15,000

LOWLAND PLAINS OR DESERTS.

81. **In the Old World** the principal plain is known as the *Great Northern Plain*, which stretches in length from the German Ocean (shores of Holland) through Prussia, Poland, Russia, and Siberia to Behring Strait, only interrupted by the transverse range of the Urals; and in breadth from the shores of the Arctic Ocean, nearly to the base of the Carpathians, in Europe, and to the table-land of Iran (Persia) and edges of the Altai Mountains, in Asia; and altogether it extends over 190° of longitude, including an area of more than 5,000,000 square miles, being nearly one-third of the area of Asia and Europe. The part in Europe is divided into the *Germanic Plain*, in the west, and the *Sarmatian Plain*, in the east; while in Asia we have the *steppes* of *Kirghis*, *Ishim*, and *Baraba*, in the south-west, and the *Siberian Plain* in the north-east.

In the *Germanic Section* occur the low-lying *polders* and *morasses* of Holland and the sandy tracts between the rivers Elbe and Weser, which are interspersed with *heaths*, *marshes*, &c. The *Sarmatian Section* extends from the Baltic to the Black and Caspian Seas and the Ural Mountains, the only interruption being the Valdai Mountains. It may be said to consist in the northern division of cold, swampy, and partially-wooded flats, much of it consisting of marsh land, and large tracts covered by peat, called *trunda*. The middle division differs much from the northern, being mild in climate, fertile, its surface undulating, richly wooded, and well watered. This is the pleasantest part of Russia. The southern division consists of steppes and river swamps, impregnated in many places with saline matter. Towards the eastern extremity the plain assumes the character of the steppes of Kirghis, Ishim, and Baraba.

Steppes, as their name implies, are wide, treeless, monotonous deserts, covered with long coarse grass and shrubs during a brief summer, and in the winter converted into bleak wastes. These steppes are estimated to cover an area of one million square miles.

Landes, or *heaths*, are those extensive areas of sand-drift which stretch southward from the mouth of the Garonne, on the coast of the Bay of Biscay. They are sometimes marshy, but mostly covered with dwarf shrubs (sea pine) and heath.

Polders are flat tracts of land in Holland, reclaimed from the sea and protected by *dykes* or embankments.

Dunes are hillocks of drift-sands, as those which stretch along the coast of the Netherlands and North of France. The minor ones of Europe are the plains of Lombardy, watered by the Po, and those of the Middle and Lower Danube.

Among the other secondary plains of the Old World may be noticed the Plain of China, occupying 200,000 square miles; the plains of Hindostan, extending from the base of the Himalayas to the Deccan, and from the Ganges to the Indus (this plain is often inundated in its lowest parts during the rainy season); the plain of Turan (1,000,000 square miles), extending along the southern shores of Lake Aral to the Caspian Sea; and the plains of Mesopotamia (165,000 square miles), in Western Asia, between the Euphrates and the Tigris. In Africa, the Desert of Sahara, which has been till of late considered a depressed plain, consists of an elevated plain, the mean height of which is about 1,000 feet.

New World.—Between the Rocky Mountains and the Alleghany Mountains, in North America, from the Arctic Ocean, is one very large central plain, watered at the lower part by the Mississippi and its tributaries, and containing some of the largest fresh-water lakes known. This plain may be said to extend to the most southern part of America—Tierra del Fuego—the only interruptions being in the case of the Gulf of Mexico and the Caribbean Sea. Its different portions are called prairies,* or savannas.† In the Southern Continent it is situated between the Andes and the Cordilleras of Brazil. The entire length of this one plain is about 9,000 miles.

The Atlantic Plain lies between the Alleghanies and the Atlantic Ocean, from the Gulf of Mexico to Massachusetts.

The Central Plain of South America is divided into three well-marked river plains—viz., those of the Amazon, Orinoco, and La Plata—termed respectively *selvas*, *llanos*, and *pampas*. The first (*selvas*) comprise the largest river basin of the world (1,500,000 square miles), covered by an immense forest, presenting the rankest luxuriance of forest growth, which in many places is so tangled with the underwood, &c., that it can only be penetrated by the river courses. The *llanos*, or grassy flats, occupy an area of 160,000 square miles, and form the lowest and most level tracts in the world, not varying a single foot for hundreds of miles. In the wet season these are inundated, and a rich alluvial deposit is formed, which, after the subsidence of the water, is quickly covered with verdure, so that the natives term it the *Sea of Grass;* but it does not last long, as the droughts which follow soon cause it to become parched and to wither away. The *pampas* comprise the basins of the Parana, La

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* Prairie, an extensive meadow. † Savanna, a bed-sheet or meado.

Plata, Uruguay, &c., and cover an area of about 880,000 square miles. They consist of rich alluvial soil, generally covered with tall grasses, thistles (some 10ft. high), weeds, &c., though in some places they are saline and barren. The desert terrace land of Patagonia, stretching 800 miles from Rio Colorado to the very end of the continent, is a sterile country, consisting of shingle, strewn with boulders, &c. With its fierce hurricanes, hot winds, and chilling blasts, it is one of the most desolate regions on the globe.

Valleys are of several kinds. Some are valleys of erosion, having been caused by the intermittent action of running water wearing away and carrying off the fragments of rock, forming deep and narrow *ravines*, which gradually widen into a valley; others, according to the theory of depression and emergences, would owe their origin to some part having been raised or other parts depressed; and others would be caused by the mountain torrent, which receives the product of the springs, snows thawed, rains, &c.

Cañons are narrow channels cut out by the rivers themselves, the water occupying the bottom from side to side, an example of which is the River Colorado, rising in the Rocky Mountains. The *Grand Cañon* of this river is 240 miles long and from 2,000 to 4,000 feet deep.

THE OCEAN.

The waters of the globe, as previously stated, cover about 145½ *millions of square miles*, which all over the earth follow the well-known law of fluids, namely, that of assuming a *uniform or natural level* at a nearly equal distance from the centre of the earth. Though the ocean has different names in different parts of the world, yet, in reality, there is but one ocean. Its form and various divisions can be best learned by inspecting a map of the world, going over it several times until quite familiar with every arm or inland sea. The ocean is one of the greatest modifiers of the climate. (See "Climate.")

82. Density of the Oceans.—Sea water has a greater density than fresh water, varying with the amount of salts dissolved in it. A cubic foot of fresh water weighs 1,000 ounces, but the same quantity of sea water weighs 1,026 ounces, its specific gravity being called 1·026; that is, taking fresh water as the standard of comparison, or 1.

The specific gravity is found to be greatest when the winds are constantly blowing over the surface, as, for instance, in the trade wind regions of the North and South Atlantics. The Pacific—especially the Western Pacific—has a relatively low specific gravity. The specific gravity becomes less as we approach either pole, where much rain falls, and where snow and ice are continually melting, and near coasts where rivers enter the sea and the winds are variable. There is also a band of low specific gravity in the equatorial region of the Atlantic. This no doubt arises from the large quantity of rain which falls in this region of calms between the north and south trade winds, and also from the water coming from the coast of Africa.

The densities of the oceans are as follow: North Atlantic, 1·02664; South Atlantic, 1·02976; the North and South Pacific respectively, 1·02548 and 1·02658; the Indian, 1·0263; Mediterranean, 1·0289; Red Sea, 1·0286; and the Baltic, 1·0086.

Sea water does not freeze so soon as fresh water (which freezes at 32°F.), but remains in its fluid state until the thermometer reaches 28½°F., or even lower; hence it is much more serviceable for man. There is another most important difference in the condition of sea water and fresh water as regards temperature below 40°. Fresh water, as stated on page 34, when cooling continues to contract until it attains a temperature a little below 40°F. If the water still continues to diminish in temperature it will now begin to expand until reaching the freezing point or 32°F. This is not the case with sea water. Sea water continues to contract down to its freezing point; the more it is cooled the heavier it becomes, because its bulk diminishes. It therefore sinks in proportion to its degree of coldness. Hence the *coldest* water is at the bottom. A curious consequence of this is that ice in sea water *begins* to form at the bottom. It may not always do so, because where ice is once formed on the surface it will extend from the previous formation; but Arctic voyagers and Baltic fishermen are well acquainted with the fact that when the season is first changing, and ice about to form, in the first instance it comes up from the bottom in little discs, like so many jelly fish, and floats on the surface.

Another point worthy of notice is that it is less vaporisable than fresh water, causing a less amount of moisture to be carried from its greater expanse to the comparatively smaller expanse of land.

83. Depth, Pressure, and Weight of the Water.—The recent soundings of the Challenger prove that our former idea of the depth of the ocean was far in excess of the truth, the deepest cast being 4,575 fathoms, and the average depth 12,000 feet, or $2\frac{3}{11}$ miles; hence its cubic contents equal $145{,}500{,}000 \times 2\frac{3}{11} = 330{,}681{,}818$ cubic miles, or, in round numbers, 330 millions. The weight from the above data may easily be found, but to have it correct we must also take into account the *pressure* at its mean depth, namely, of one mile; the weight of a column of sea water of this height is $1760 \times 3 \div 33·8$ (height of a column of water equal to the weight of the atmosphere) = 156·2 atmospheres; this weight is sufficient to compress the water at that depth about ·0142,* so that its density will be 1·04076. Thus, sea water at its surface has a density of 1·026 (pure water being 1), but owing to the compression (1 − ·0142), or ·9854 cubic feet, at the mean depth, has this density; hence one cubic foot has a mean density of 1·026 ÷ ·9854 = 1·04076, supposing the depth to be two miles. At this density a cubic foot of sea water weighs 62·5 (the weight of a cubic foot of pure water) × 1·04076 = 65·0675lb., and a cubic mile (5280^3 × 65·071b.) = 4,275,969,078 tons; hence, entire weight of the ocean equals this number multiplied by the number of cubic miles, viz., 330 million, which gives 1,411,070 billion tons, or about $\frac{1}{4147}$th of the whole globe.

84. Its Composition and Saltness.—(For composition see 45.) The saltness is caused by the presence of soluble matter, as *sodic chloride* (common salt), which exists in a greater quantity than any other saline material (about 2·8 per cent), next to which in abundance come *magnesia*† and *lime*, which occur as carbonates, sulphates, and chlorides; then follow *soda*, *potash*, *iron*, *silica*, various iodides, &c. Silica and carbonate of lime play an important part in nature, supplying the skeleton, or hard parts of fishes, shells, and other marine organisms, such as form the bottom of the ocean for thousands of square miles.

Generally speaking, the ocean is of a uniform degree of saltness, containing from 3½ to 4 per cent of saline material, although in gulfs, land-locked seas, &c., there is a comparatively slight difference, when compared with the ocean. Inland seas, receiving many rivers, and subject to but little evaporation, are generally fresher;—for instance, the Baltic, which is only half as salt. Again, the Mediterranean, although many large rivers enter into it, is very nearly twice as salt as the English Channel. The Red Sea has also an excess of saltness, owing, no doubt, to excessive evaporation, and the Polar Oceans, owing to the melting of the ice in summer.

Taking the specific gravity of the saline materials at 2, which is not far from the mark, a cubit foot would weigh 62.5 × 2 = 125lb.; hence one cubic mile weighs (5380^3 × 125) = 8,214,171,428·57 tons, but the salt is equal to 3½ per cent of the whole cubic contents, namely, 11,573,863 cubic miles, so that the weight of salt is (8214171428 × 11573863) or 95,069,694,766,186,364 tons, or 95,070 billion tons nearly.

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* It has been found by experiment that for every 1,000 feet of depth, water is compressed $\frac{1}{340}$th of its bulk.

† It is the chloride of magnesium which causes the clothes of sailors, when wetted with sea water, to have that damp, sticky feeling.

The amount of salt in the ocean must ever be on the increase, as the rivers in their journeys through the land wash out such soluble substances as salt, &c., and carry them into the sea, where very nearly all rivers run. When once there it must remain, as in the process of evaporation *fresh water* alone is taken, which in its turn returns with its saline substances.

Colour.—Though in small quantities the waters of the ocean appear colourless, in large masses it is of various hues. For instance, in the open sea, it is of a deep blue colour, while in the shallow parts it appears green. The cause of these colours has not been satisfactorily explained, some thinking that they are due to the different degrees of salt in the water. There are a few sheets of water which take their names from their colour, as the *Vermilion Sea* (Gulf of California), the *Yellow Sea,* whose colour is due chiefly to the sediment discharged into it by the rivers ; the *Green Sea* (Sargasso Sea), *Red, Black, White Seas,* &c., whose hues are probably due to the presence of solid matter, either as living organisms or as sediments.

85. Depth of the Ocean.—Previous to the late expedition, our knowledge respecting the depth of the ocean was very meagre. The soundings taken by the Challenger, together with those obtained by the Americans and Germans, have furnished us with many observations respecting it. The greatest depth ascertained by the Challenger (as previously mentioned) was 4,575 fathoms in the western part of the Pacific. According to the Americans, a depth of 5,000 fathoms was found off the coast of Japan. The average depth of the North Atlantic is about 2,000 fathoms, and that of the Pacific probably nearly 3,000 fathoms, so that the average depth of the entire ocean may be taken at 2,500 fathoms or 15,000 feet. This is nearly fifteen times the average height of the land above the sea level. Still there is the curious fact, that the height of the highest mountain in the world is just about the same as the greatest depth which has yet been ascertained.

It has also been noticed in these ocean depressions, such as those mentioned above, low submarine ridges are met with. These rise in some places to within two miles of the surface of the sea, thus, for instance, such a ridge runs north and south throughout the whole length of the Atlantic, from Greenland to Tristan. On this ridge the islands of St. Paul, Ascension, and the Azores are found.

From this ridge a branch runs about 10° north towards the West Indies, thus separating the bed of the Atlantic into three depressions. Similar ridges are to be found in the Pacific ; thus one probably surrounds the Coral Sea to the east of Australia, another runs in the direction of the Caroline Islands and Ladrones, while the Friendly, Fijis, and New Hebrides are connected by another. These ridges have an important influence on the distribution of temperature over the bed of the ocean.

Generally speaking, the oceans have a true basin-like character. Thus, proceeding from the shore of a continent, we usually after passing the 100 fathom line, find the depth to increase very rapidly down to a depth of two, three, or even more miles. It is also noticed that when the land gradually slopes toward the ocean the water deepens gradually, but when the land descends precipitously, the sea deepens in like manner suddenly and abruptly. Thus, on leaving Ireland to cross the Atlantic it only sinks six feet per mile for the first 230 miles, afterwards it makes a descent of 1,400 fathoms in about 20 miles.

Ocean Deposits.—In the ocean, deposits are continually going on; thus rivers carry away from the land down into the sea substances in suspension and in solution. The substances held in suspension are deposited about the shores, and those in solution, such as silica and carbonate of lime, are secreted by plants and animals, and their remains make up a large part of ocean deposits.

In the temperate and tropical regions, at depths not exceeding three miles, the deposits are generally made up principally of the shells of the foraminifera and molluscs, and the remains of calcareous algæ. These minute animals lived on the surface of the water, and it is their dead remains which we find at the bottom. When the deposit consists principally of the foraminifera, it is termed a *Globigerina ooze;* when the pteropods preponderate, a *Pteropod ooze.* The *Globigerina ooze* covers the floor of the great part of the *North Atlantic Ocean.*

The *Globigerina* when alive are about the same specific gravity as water, their weight being reduced by small oil globules scattered through their substance. They are thus enabled to live at or near the surface. When they die the oil disappears, and their shells slowly sink to the bottom. It is most probable that in this way the beds of limestone and chalk have been formed, as the ooze consists almost entirely of carbonate of lime. Indeed we may consider this Atlantic mud to be a continuation, so to speak, of the old chalk. Another kind of deposit termed the *Radiolarian ooze* is found in some parts of the middle and western Pacific. It occurs in patches on the red clay at very great depths. The *Radiolaria* are minute organisms with silicious instead of calcareous shells.

In the Antartic Ocean the deposit is almost entirely made up of the frustules of *diatoms* which had lived at the surface, and after death fallen to the bottom. This is called a *diaton ooze.*

These diatoms are very minute, and vegetable products. During life they are covered with a greenish body-substance, but this encloses a beautiful glass-like skeleton of silex. By far the most abundant oceanic deposit is red or chocolate-coloured clay. These deposits are found in the Pacific at depths greater than 2½ miles, and far from land. This clay is supposed to be of volcanic origin. The Pacific is fringed with active volcanoes, and in the Atlantic there are also active volcanoes in many of the islands. These during eruption throw out liquid lava. Some of this cooling rapidly in the air forms pumice stone, which is very light, and may be carried a great distance by wind and waves. In many volcanic regions immense deposits of pumice are to be found. Rivers in cutting through these deposits carry large quantities of pumice stone out to the ocean. Here the stones float about till they become waterlogged, and sink to the bottom. The carbonic acid of the ocean water acts on the felspar of those stones, and they are decomposed. Lime and magnesia are removed, water is taken up, and a silicate of alum is the result.

Further in these clays are crystals of sanadin, quartz, augite, and others, and these same crystals are found in the floating pumice-stone. The calcareous shells which live on the surface of the water, and fall to the bottom after death, are removed in the greater depths of the ocean by the action of carbonic acid in the sea water, being converted into a bicarbonate which remains in solution. It has been noticed that when the carbonate of lime organisms are very abundant on the surface, the calcareous deposits occur at much greater depths than when they are relatively less abundant.

In these areas of great depth far from land, the chief things which fall to the bottom are pumice-stones, and the result of their decomposition, clay—volcanic ashes, and dusts from deserts caused by winds. In these same areas, which are areas of exceedingly slowly accumulating deposits, other chemical changes take place. Another of the products of the decomposition and disintegration of the loose volcanic materials at the bottom is peroxide of manganese, which is deposited in concretionary form around substances at the bottom, such as sharks' teeth, ear bones, &c.

In the clays and in the nodules from these regions have been found spherules of native iron, nickel, and other magnetic spherules, which appear to have fallen from the interstellar spaces—cosmic dust, in short. Arranging the deposits according to the depths at which they are found, we shall have first, shore deposits found in shallow water near the shores, consisting of blue, green, and yellow muds about the shores of continents, coral muds, grey muds, and sand about oceanic islands; then, the siliceous deposits of diatoms, which are to be found in the Antarctic Ocean; next, the calcareous deposits of the Globigerinæ; then the red and chocolate clays; and lastly, the siliceous deposits of the Radiolariæ.

Animal Life of the Ocean Depths.—Until within a comparatively small number of years. it was considered that marine oceanic life was limited to a depth of about 300 fathoms. This doctrine has been proved entirely incorrect. Thus, when soundings were taken in the Atlantic, with reference to the laying of the Atlantic Cable, specimens of marine animals were brought up from the bottom. The deposit forming the bed of that part of the ocean, when examined with a microscope, was found to consist of minute shells of globigerinæ, so small that thousands of them would scarcely weigh a grain. Larger animals were also brought up. Between the Faroe Islands and Iceland, the sounding line brought up, clustering round it, a group of star fish from a depth of 1,200 fathoms, the stomachs of which were filled with globigerinæ, showing that they lived at the bottom. There were also found some small crustaceous animals of the shrimp kind, and small marine worms—tubes of marine worms built up of globigerinæ that must have been at the bottom.

In the Lightning expedition, Dr. Carpenter, says, "we found on a warm bottom a great abundance of animal life at from 500 to 600 fathoms, with a number of most remarkable new forms, amongst others a most beautiful sponge, four specimens of which were discovered embedded in the chalky mud, mixed with sand, at a depth of 530 fathoms." In the Challenger expedition there was brought up from the depth of 2,435 fathoms, a hundred weight and a half of this globigerina mud, with a number of animals included in it, specimens of the deepest life which has been obtained from the sea bed. It is no doubt to the general circulation of the water that the creatures that live in the depths of the sea owe their existence. If the waters from the surface did not sink down and carry with them fresh oxygen and vegetable and animal matter, these creatures would perish as in a stagnant tank.

It was also found, that the minute *algæ*, called oscillatoriæ, are generally present in the warmer regions, and sometimes so abundant as to discolour the sea. Diatoms are universally distributed, being found in those places where the specific gravity of the water is low, as for instance, in the Antarctic regions. The diatoms and other minute plants are primarily the food of all deep sea animals. They appear to be confined to the surface layers of the ocean, as no living plants were found in the deep water.

86. Instruments and Method of Investigation.—It is only recently that the art of sounding has been so perfected that the results may be relied on. When the line with sinkers attached was let down under the old system, there was the uncertainty as to whether the weights had touched the bottom or not, and supposing that the weight had touched the bottom, and that the line was tense throughout, it would be questionable whether the vessel had moved its position during the operation—and again, supposing that the weight had touched the bottom, it was doubtful whether the length of line did not far exceed the vertical depth. To obviate these obstacles several plans have been devised. Thus, for instance, Sir Wm. Thomson's patent sounding apparatus, which is founded on the fact that the pressure of the water increases in a certain definite ratio to the depth. If the pressure is known, the depth may be calculated therefrom. The apparatus used by the *Challenger* consisted of a long cylinder, about two inches in diameter, fitted with a common butterfly valve at the lower end, and attached to a strong sounding line—made either of rope or wire. Around this tube three or four sinkers of iron are arranged, and are supported in this position by a strong wire, which is passed over "catches" at the upper end of the cylinder. The tube is made to project about eighteen inches beneath the sinkers.

The sounding line, with the apparatus attached, is allowed to run out freely, and a depth of one mile is reached in about nine minutes, two miles in about twenty minutes, three miles in thirty-five minutes, four miles in fifty-five minutes, and the deepest sounding of a little over five miles, in about seventy-five minutes. When the sinkers strike the bottom the wire detaches itself from the catches, and they drop off. The tube is at the same time forced into the mud or clay, so that when it is drawn up, a specimen of the bottom is obtained. Attached to the sounding is a thermometer to register the temperature, a water bottle to obtain a sample of the water at the bottom, as well as the pressure gauge to register the pressure of the column of water.

The Pressure is Found thus.—A brass tube, open at the top, but closed at the bottom, is fixed to the sounding line wire. Inside this tube another smaller one of glass is inserted, which is closed at the top and open at the bottom. In the brass tube is some sulphate of iron, and the glass tube is coated with a solution of prussiate of potash. As the weight sinks, the water presses more and more, causing the sulphate of iron to be forced into the glass tube—then, acting chemically upon the prussiate of potash turns it into a deep blue colour. The sulphate of iron is forced up in the glass tube to a height depending upon the degree of pressure in a vertical line above it. The wire and attached tubes being drawn up, the glass tube is laid on a graduated scale, and the degree of pressure as shown by the height of the red column may be read off.

The THERMOMETERS used are specially constructed for the work, and are called "protected thermometers," that is to say, the bulb which contains the mercury, or other fluid by whose expansion the the temperature is measured, has a second bulb blown around and outside it. This second bulb protects the inner one from the great pressure to which it would be exposed in deep water. In this way the record of the instrument is not affected by pressure, the whole rise of the mercury in the tube being due to the heat which reaches the inner bulb.

The WATER BOTTLE is a heavy metal cylinder, so constructed that it shuts up when it reaches the bottom, enclosing about half a gallon of water. In the upper end is a small tube so as to allow some water to escape from the bottle, otherwise the bottle would burst on being drawn up, owing to the greatly diminished pressure on the outside as it approached the surface.

Besides the sounding line with its attached instruments, trawls, dredges, tow-nets, &c., were used to catch specimens of small plants and animals which live at various depths. The trawl has a beam of twelve or fifteen feet, to which is attached a double-pocketed net for about thirty feet. On to the bottom of the pocket a piece of coarse cloth is sewn, so as to retain the mud and small things which may be caught up by the net as it drags over the bottom.

The dredge has a frame of about five feet by nine inches, from which hangs a net, at the bottom of which is a piece of cloth, as in the trawl. Beneath the netting an iron rod is supported by means of strong ropes to the iron frame, and to this rod are fixed large hempen tangles or swabs. These swabs frequently bring up things missed by the dredge. The trawl when at the bottom is allowed to remain for two or three hours. It then takes five or six hours to haul it up from a depth of about three miles. Its contents, generally consisting of a large quantity of red or blue clay, or of ooze, are minutely examined.

87. Temperature of the Ocean and Oceanic Circulation. The information obtained by the Challenger tends to show that by far the greater part of the water of the ocean has rather a low temperature. Generally speaking, the water is warmest at the surface, where it is affected by the latitude of the place, the season of the year, and ocean currents. From the surface it cools rapidly for the first five or six hundred fathoms, at which depth it has a temperature of about 40° F. It then cools very slowly down to the bottom, or down to a point from which the temperature remains constant, varying from 35° down to 32° F.; even under the equator the water at the bottom has been found to be 32° 7′. In the temperate parts of the North Atlantic Ocean, before the temperature of 40° is reached, a depth of a mile or even more must be descended; but in the tropical and south temperate regions of the Atlantic, and throughout the tropical and temperate parts of the Pacific, this temperature is reached at a depth of half a mile, or a little more. Near the Polar regions the temperature of 40° is met with at the surface.

It is now generally admitted that there is a flow of cold water from the Antarctic Ocean, which flows slowly northward under the stratum of warmer water, that is, below the *isothermobath* (or line of equal temperature in the sea) of 40° F. Sometimes this water meets with a barrier—the lower and colder water is then stopped, and the basin beyond is filled with water of the same temperature as that at the top of the barrier. Thus, for instance, the cold water which flows from the Antarctic along the eastern coast of South America, where there is free communication with the south, has at the bottom a temperature of 31° F., while in the basins to the north and east of the Atlantic, we have at the bottom, and also from the depth of about 2,000 fathoms down to the bottom, a temperature of only 35°. The reason of this is, because these basins are cut off from the Antarctic sea by ridges, whose tops are about 2,000 fathoms from the surface of the water. Hence these basins are filled with water, having the temperature the same as that found at the same level as the lowest point of these ridges. In like manner, the Coral Sea is cut off from the general circulation of the Pacific, hence its water is of a uniform temperature below 1,400 fathoms. We therefore see that the low submarine ridges which are found throughout the ocean basins, have an important influence on the distribution of temperature at the bottom of the sea.

88. Oceanic Circulation.—Many theories have been advanced to account for the flow of the cold water of the Antarctic Ocean northward into the deeper parts of the Atlantic and Pacific. Thus, Dr. Croll, in the *Philosophical Magazine*, advocates the theory—that oceanic currents are due to the action of winds, or, in other words, that the general system of oceanic circulation is produced by the combined action of all the prevailing winds of the globe regarded as one system of circulation, and not by the trade winds alone, nor, by the prevailing winds proper alone.

He argues, the direction of the chief currents of the globe and that of the prevailing winds agree exactly. Thus, the Gulf Stream follows the path of the prevailing winds, and like the wind, divides into two branches in Mid-Atlantic, one branch journeying north-east, and the other south-east, that is, in exactly the same direction as the prevailing winds; and other similar cases he brings forward.

Another theory is that advocated by Sir W. Thompson, namely, the *precipitation theory.* He is of opinion that the circulation is kept up by the excess of evaporation over precipitation in the Northern, and the excess of precipitation over evaporation in the Southern Hemisphere—part of the circulation taking place, in short, through the atmosphere.

Dr. Carpenter advocates what is called the *gravitation theory.* He thinks the greater pressure of the column of cold water in the Polar regions keeps up the general circulation. Thus, according to his theory, there are two primary sets of currents in operation—a surface current of warm water flowing from the Equator to either Pole, and an under current of cold water from either Pole to the Equator. It is to the Polar cold that Dr. Carpenter attaches most importance, much more than to Equatorial heat. He endeavours to show that the whole mass of water from top to bottom is influenced by the former, whereas the influence of the latter does not exceed 100 fathoms in depth. The surface water in the Polar regions on being cooled to near the freezing point becomes heavier, and naturally sinks. The next layer is then exposed to the same cooling influence. This in its turn sinks. This process continuing, the equilibrium of the water is disturbed, so that a stratum of surface water flows in to restore equilibrium by taking the place of that which has sunk, and moved along the sea bottom towards the equator.

89. Movements of the Ocean.—The movements of the ocean are of three kinds—namely *waves*, *tides*, and *currents.* These motions arise from the influence of the winds, the attraction of the sun and moon, and from the temperature.

Waves are undulations of the water without progressive motion, produced by the wind. They vary in size according to the force of the wind, from a gentle ripple, to billows 40 feet in height, though a wide expanse is requisite to produce its full effect. The highest waves known are those which occur off the Cape of Good Hope and Cape Horn, where they attain sometimes between 30 and 40 feet from trough to crest; but the depth to which the disturbance is felt is very slight. The velocity of waves, or the rate at which they travel, depends upon the breadth and depth, as a *wave of a certain breadth* cannot attain more than a certain velocity, and if the *depth is less than the breadth* this velocity cannot be attained. It has been calculated that a wave 1,000 feet broad, formed on water 10 feet deep, travels 12 miles an hour ; on water 100 feet deep, 36 miles an hour, or 53 feet per second ; on water 1,000 feet deep, 49 miles an hour. If the wave was 10,000 feet broad, in the depth of 10 feet its rate would be 12 miles an hour; in 100 feet, 39 miles an hour; in 1,000 feet, 115 miles an hour; and in 10,000 feet, 154 miles an hour.

It is not the water which travels at these rates, but simply the *form* of the water, which rises up and down. This motion is well imitated by shaking the ends of a stretched rope, giving rise to a succession of waves, or also in the shaking of carpets, when the two ends held in the hands remain fixed, while *waves* are propagated from one end to the other. The waves coming near the shore are interfered with in their rising and falling by the water causing the foot of the wave to be held back, and the head to curve forward, and *break* with great force—the momentum in some cases being that great that large masses of stone or concrete, even weighing as much as 50 tons, are torn down from piers and breakwaters. The effective pressure of these breakers has been estimated as high as 6,000lb. per square foot.

90. Currents, their Causes, &c.—Currents are movements in the ocean, like great rivers, transporting the waters from one region to another. These currents, like the winds, are arranged as *constant*, *periodical*, and *variable*. The theories respecting the general circulation are briefly stated in the preceding article, but each of these classes is affected in some way peculiar to its own class. Thus the *constant* depend chiefly upon the unequal temperatures and densities in the waters of the ocean, the rotation of the earth, and the trade winds. The heat of the sun at the tropics heats and expands the water there to a considerable depth; at the same time the cold at the poles renders the water heavy and dense, causing it to sink and flow below the warm water lying near the equator, while the lighter water of these regions flows over towards the poles to restore equilibrium. These currents do not flow exactly north and south, but are deflected in like manner to the trade winds, the polar currents tending to the west and the equatorial to the east (see 115), forming, the same as in the air, *four great currents*. The *periodical* currents are caused by the tides, monsoons, sea and land breezes within the tropics, &c. They are most common in the Indian Ocean. The *variable* currents are those produced by local peculiarities in the tides, winds, melting of ice in the polar regions, and other such causes. *Drift* currents, due to the long-continued agency of the wind, affect only a very trifling depth. *Deep sea currents*, as their name indicates, penetrate to great depths, namely, hundreds of fathoms below the surface.

The currents of each ocean will be described in their proper place, under each ocean. (For situation and extent of the ocean, see 67.)

THE ATLANTIC OCEAN.—We will notice this one first, not on account of its size, but of its great importance to us. This ocean is calculated to drain more than 19,000,000 square miles of land. It is also distinguished for its fewness of islands but numerous gulfs and arms. Its average *depth*, as ascertained by the Challenger, is about 2,500 fathoms, or 15,000 feet, its greatest known depth being 3,916 fathoms, or 23,500 feet. In the northern part, near the middle, it is a flat plain, running north and south, the average depth of this plain being about 1,800 fathoms, though at each side, and south of the equator, it is, on an average, about 2,800 fathoms. Round the British Isles the portions of this ocean are not very deep, no part of the German Ocean exceeding 70 fathoms; and the deepest between Dover and Calais does not exceed 30 fathoms. The *temperature* of the upper layer of about 100 fathoms deep, may be said to average between 75° and 80° in summer, ranging down to about 55° in winter. Below this depth the effect of the sun is not felt, sinking

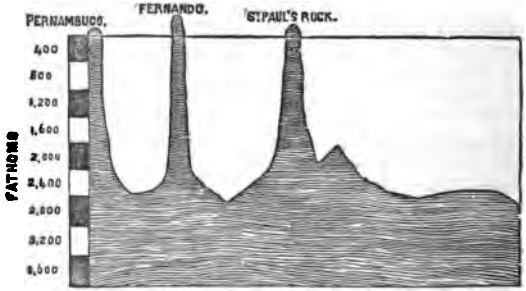

Fig. 9.—Section of Equatorial Atlantic.

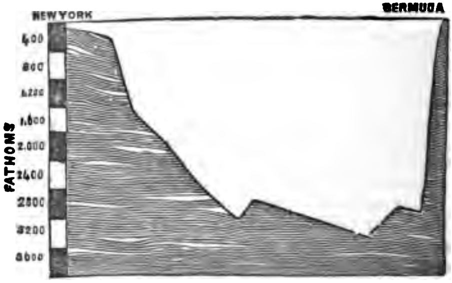

Fig. 10.—Section of the North Atlantic.

from 55° at 100 fathoms to about 35° at 2,000 fathoms. The S. W. Atlantic is still colder, the bottom water averaging from 31° to 33½°.

The principal branches and inlets belonging to this ocean are the North Sea, Baltic Sea, Irish Sea, the English Channel, the Bay of Biscay, the Mediterranean, &c., on the east side; Hudson Bay, Gulfs of Mexico and St. Lawrence, the Caribbean Sea, &c., on the west. (For its chief affluents see "Table of Rivers," page 109.) Among its currents the principal and better known are the *Equatorial*, the *Gulf Stream*, the *Arctic*, the *Guinea*, and the *Brazil*. The first, as its name implies, occurs chiefly in the region of the equator, flowing along the western coast of Africa, and crossing the ocean towards the American continent. After traversing a little more than half way it divides into two branches, one going northward by the coast of Guiana into the Caribbean Sea, the other, the weaker part, travelling southward along the shores of Brazil. This equatorial current, from the coasts of Africa to the Caribbean Sea, is nearly 4,000 miles in length, and varies in breadth from 150 to 450 miles. Its velocity ranges from 18 to 30 miles a day at the surface, its rate decreasing lower down till at the bottom it never exceeds 12 miles. The *Gulf Stream* is by far the most important current of this ocean. It leaves the Gulf of Mexico, and travels through the Strait of Florida at a mean velocity of 46 miles a day, its average temperature being a little over 80°. Flowing northward, almost parallel with the American coast, at latitude 40° north it turns to the east, touching the south banks of Newfoundland, and proceeds across the Atlantic to the Azores, where it divides into two large branches, one going north-east and onward till it reaches the Arctic Ocean, and the other south-east to the west coast of Africa. The entire length of this vast river, from the Gulf of Mexico to the Azores, is 3,000 miles, and its greatest width about 112 miles. Its velocity gradually diminishes from 46 miles a day at starting to 18 at the Newfoundland banks, still getting weaker as it crosses the Atlantic and also decreasing in temperature, gradually diffusing its heat all around.

The water of this stream is salter than that of the common sea water, of a more bluish colour, and posses very little affinity for the ordinary water; even so that in many places you may see with the naked eye where, on either side, it touches the neighbouring water. It is owing to this stream that many places may enjoy a summer climate all the year round, as on the coast of France. England enjoys a temperate climate owing to the same cause; while other places in a *lower latitude* experience much more severe winters, &c. (See "Climate" 134.)

The *Arctic current* of cold water flows along the east coast of Greenland; being met by another south of Cape Farewell from Davis Strait they flow on southward towards the Caribbean Sea. It divides on meeting the Gulf Stream, part flowing to the Caribbean Sea, entering as an *under current*, the other part journeying south-west, forming the United States *counter current*. It is this current of cold water which replaces the warm water sent through the Gulf Stream, and also modifies the climate of all the United States coast-line, &c.

THE PACIFIC OCEAN.—It is in this ocean that the *greatest depth* has been found in the late expedition, viz., north of Papua, in lat. 11° 23′ N., long. 143° 16′ E., the depth being 4,575 fathoms, or 27,450 feet, about 5½ miles. The average depth of the South Pacific is about 2,000 fathoms, and that of the North Pacific about 3,000 fathoms, increasing gradually from south to north. The surface temperature of this ocean may be taken in summer at about 80° F.; at a depth of 80 fathoms near Tahiti it is 77° F., but 500 fathoms deep the temperature is uniformly about 44° F.; at a *greater depth* than this it falls gradually to 36°, and sometimes even to 32°.

The chief branches and arms are: Behring Sea, the Gulf of California, and Bay of Panama on the east, and Sea of Japan, Yellow Sea, China Sea, &c., on the western side. This ocean contains a vast number of islands, both of volcanic and coral formation. A glance at a map will be of more service than a written description of their situation. The chief *current* is the *equatorial*, which originates in the *Antarctic drift current*, flowing north-east till near the coast of Chili, where it divides, sending one branch round by Cape Horn, and forming the current of that name. The other part travels northward, forming the *Peruvian current*, which is so remarkable on account of its cold stream along the hot coast of Africa. On the Peruvian coast, in lat. 18° S., it has a temperature of 14° below that of the neighbouring ocean, and even at lat. 8° S., where it branches off to the west, joining the great *equatorial current* of the Pacific, its temperature is between 9° and 10° colder than the other water. The chief current now continues until it forms, northward of the Philippine Islands, the *Ja an current*, or what we may term the Gulf Stream of the Pacific—it now performing similar duties to the one of the Atlantic. Travelling nearly to the Aleutian Isles, it sweeps round and returns to the equatorial current. The southern part of the equatorial current journeys along southwards to the coast of Australia under the name of *New South Wales current*, and then wends its way to the Antarctic Ocean.

THE INDIAN OCEAN.—The greatest depth hitherto known in this ocean was 2,340 fathoms, or 14,040 feet, lying to the east of Ceylon, long. 85°; but from recent occasional soundings the depth of more than 20,000 feet has been ascertained in the south-west portion of this sea. The principal branches and arms of this ocean are the Arabian Sea, Persian Gulf, Gulf of Oman, Gulf of Aden, Red Sea, Mozambique Channel, &c., on the west; the Bay of Bengal, and the Great Australian Bight, &c., on the east. The equatorial current in this ocean travels westward from the Indian Archipelago and Australia to the east coast of Africa, where, divided by the island of Madagascar, one branch flowing round the north of the island, forming the *Mozambique current*, the other southward towards the Cape of Good Hope, they again unite, forming the *Cape current*, part of which flows northward into the Atlantic, while the chief part is deflected to the east by the Agulhas Bank, and flows to Australia. This current is of much importance to vessels on their journey to Australia, travelling as it does at the rate of about 4½ miles per hour.

THE ARCTIC OCEAN.—This ocean does not appear near so *deep* generally as those previously mentioned, especially in the higher latitudes. The temperature reaches in the lower parts as low as 72° below zero, but in the summer about 32° at the surface. The chief branches are the White Sea, the Gulfs of Kara, Obi, Yenisei, and Behring Strait, in the Old World; and Melville Sound, Barrow Strait, Baffin Bay, &c., in the New World. The comparatively warm Gulf Stream flowing into this ocean causes the colder water to flow off as the *Arctic current*. (See "Atlantic Ocean.")

THE ANTARCTIC OCEAN.—This ocean has not been traversed as far as lat. 80° on account of its being much colder than in the Arctic Ocean; but the part that is known is much deeper than the water at its antipodes, the greatest depth being 1,975 fathoms, or 11,850 feet. The *temperature* of the water is lower here than in any other ocean. The surface water in February, in latitude 5¼° S., and longitude 79° 50′ E., was about 28½° F. in the pack ice; but a short distance from it the temperature was found to be 32° F., gradually sinking as the depth increased, till, at 40 fathoms deep, it was 29°, this temperature remaining constant for 260 fathoms deeper, when it began to rise, reaching 32° or 33°. In this ocean several valuable ocean currents have their origin. One of the chief is the *Antarctic drift* (which is described under the name of Equatorial current), in the Pacific.

Inland Seas.—The Mediterranean Sea, between Europe and Africa, has an area of about 950,000 square miles; mean depth 1,200 fathoms, varying from 300 to 500 at the Strait of Gibraltar to 2,000 fathoms in the east. The average temperature is 60° to 70°. The Black Sea, including the Sea of Azov, has an area of 185,000 square miles; depth about 50 fathoms. The Caspian Sea may be regarded as the greatest salt water lake in the world. It is situated 81 feet below the sea level; its area is about 177,000 square miles, and the depth varies from 8 fathoms in the north to 450 in the south; the mean temperature is about 56°. The Red Sea has an area of 175,000 square miles; the average depth is 200 fathoms; temperature, 96° to 106° F. The Baltic Sea has an area of about 162,000 square miles; average depth about 800 feet; average surface temperature 35° in the north and 45° in the south.

91. Action of the Sea on the Earth's Crust.—The sea coasts are subject to the erosive and destroying movements of the ocean, especially *breakers*, which are aided in their action by the tides. These breakers, which are simply the wind waves (which see) formed on the surface of the sea during storms, acquire immense force, and break with violence on the rocky shores. One thing that assists marine denudation much is the fact of large stones or any matter having from one-third to one-half of their weight balanced by the buoyancy of the water. Hence the breakers have only about half the work to do to remove the stones, &c., when in the water. The work of the sea on the coast is not that of carving or cutting out, but simply that of *levelling*. The rate at which the sea wastes the land deepens on its nature, and also on the alterations of the rocks of the coast, as well as on the force and direction of the currents. Thus on the east coast of this country, where the rocks are principally sands, clays, &c., the destruction is very great. On the coast of Yorkshire the waste is from one to four yards per annum.

Again on the south coast we see several cliffs, headlands, &c., still standing contending against the action of the sea, while the soft sandstones have given way much more rapidly. Yet still, though these cliffs, &c., are composed of much harder rocks, they cannot hold their ground, but slowly, yet surely, are compelled to retreat before the action of the waves, which scoop them out near the ordinary sea level, causing the weight of the overhanging portion to outbalance the *cohesion* of the rocks. The force of breakers in 1829 (November) washed about like pebbles blocks of limestone and granite, from 3 to 5 tons in weight each, near the breakwater at Plymouth, carrying 300 tons of them a distance of 200 feet. Another, 7 tons in weight, was washed 150 feet up the inclined plane of the breakwater. Striking examples of the sea's action may be noticed in the many rocks which stand out in the sea detached from the main mass of land, but which have evidently formed part of it, such as the *Needles*, off the Isle of Wight, and the *Drongs* of Shetland. To the sea's action may be attributed the piling up of shingle beaches. The shingle is projected on the land beyond the reach of the retiring waves, forming in many places beaches several feet in height.

On the coast of Norway are numerous *fiords*—that is, narrow arms or channels of the sea, or the widening of a river into arms of the sea. These have been formed by the action of the sea upon the coast. The country of Norway being raised considerably above the level of the sea, the coast, therefore, offers special resistance to the waters as they rush inwards. They in their turn carry on a work of disintegration in several ways: viz., by the force of the breakers, by its action of decomposing rocks (44), by frost, &c.; so that the softer rocks have to give way to the sea, while the harder still contend against it.

WATERS OF THE LAND.

92. Springs, Rivers, Lakes, &c.—*Springs* are principally of three kinds—*land*, *artesian*, and *mineral*. The former occur in places where the bed of rock is pervious to water, being underlaid by a bed that is impervious, the rain sinking through the top layer, forming pools on the underlying impervious substratum, and when a well or a pond is dry the water collects in it. These depend almost entirely on the rainfall, and are also liable to be tainted with matter from the sewers, &c. The *deep-seated* are just the reverse of these, being but little influenced by summer droughts or winter rains, flowing steadily at all times. *Perennial springs* are those which flow year after year without any signs of abatement.

Artesian, or *Transtratic, Springs* result from one permeable stratum lying between two impermeable strata, the water piercing into the rock where the layer is at or near the surface. It then *runs through it* in the direction of the slope of the layer until it has reached the surface in some other place. It will perhaps be better understood from the following diagram, where H B represents the permeable bed

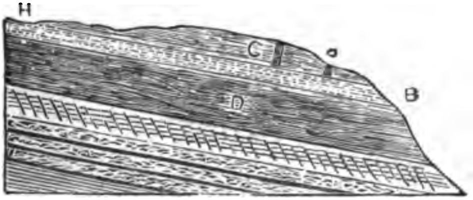

Fig. 11.

C and D the two impermeable beds which it lies between after leaving H; then, the water soaking into the earth at H, will soak down as low as possible, namely to the bed D, and afterwards gradually flow through the pervious bed H B, until it reaches B, when it rushes out as a spring. It is this class of springs which gives rise to *artesian wells*, as, for instance, suppose, as at O, the top layer be pierced down to the water-bearing strata, it is evident the water will rise at O.

Intermittent Springs also occur in various places and under various circumstances. Thus, for instance, on the banks of the Thames, between London and Richmond, the wells regularly ebb and flow with the tide, owing to the porous nature of the river's banks. Near Dynevor, in Carmarthenshire, at Tideswell, in Derbyshire, and near Settle, in Yorkshire, are springs flowing out of cavernous limestone rocks. These springs now gush with vehemence, now subside, shrink away, and disappear. The explanation most generally received supposes the water to fill cavities underground, from which the discharging channels are syphon-formed, so that at a particular moment the full cavity begins to be discharged and finally runs out, and the current then ceases till the space be again filled to the vertex of the syphon-formed arch. These springs, in their motion upwards and downwards through various mineral masses, become impregnated with gaseous, saline, earthy, or metallic admixtures, as carbonic acid gas, sulphuretted hydrogen gas, nitrogen, sulphate of lime, carbonate of lime, muriate of soda, silica, carbonate of iron, &c. Examples of these mineral springs occur at Cheltenham, Epsom, &c., where they are *saline*, containing salts. In Italy and France they are *calcareous*, containing much lime. In the latter country there are more than 900. When iron is present they are termed *chalybeate*, as at Tunbridge Wells; when containing sulphur, *sulphurous*; and when containing carbonic acid, *carbonated*. Germany and Spain have large numbers of these mineral springs, about 600 in the former country and 400 in the latter.

In Tuscany the springs contain boracic acid, from whence the greater part of this substance used in art is obtained by evaporation. The boiling waters of the Geysers in Iceland decompose the lavas and take up the silica in solution, which is deposited around the sides of the vent, forming a basin-like crater with low sides, and covering an extensive region in the vicinity with the aqueous deposition of silica, termed silicious sinter, besides petrifying wood.

On the chalk downs in the South of England it is a common occurrence for the valleys to be quite dry in the winter or autumn, and very fully watered in the spring or autumn.

Hot Springs.—At a certain depth below the surface, the temperature is uninfluenced by the change of seasons, and springs from this level are always at the mean temperature of the locality in which they are situated. This zone of uniform temperature in Great Britain occurs at a depth of about 200 feet. Below this depth a regular increase of heat is observed, about 1° for every 60 feet of descent. Springs have a temperature corresponding to the depth at which they rise. Thus at Matlock the water is at a temperature of 65°F.; at Buxton, 82°; at Bath, 117°; at Clifton, 76°.

Other hot springs are found to be connected with centres of volcanic disturbances. Thus at Lisbon, during the great earthquake, a spring called Le Source de la Reine, in the Pyrenees, was suddenly raised from 70° to 122°F.—a temperature it retains to this day.

93. **Rivers** are of great importance in nature by carrying off the surplus water into the ocean, and also by giving rise to the most fertile parts of the country. They are also of importance in a commercial respect, and the benefits arising therefrom may be noticed in such places as London, Liverpool, &c. The *basin* of a river is the *whole tract drained by the river and its tributaries*, the area of which may be found by drawing a line connecting the source of the river with the sources of all its tributaries. The elevated ridge which separates one river basin from another is term d the *watershed*, or *waterparting*, as it is now called, the former word being now used to denote the sides of the hills sloping from the ridge towards a river. To have a good knowledge of all the chief slopes, &c., the student should consult a good map of the Physical Features of the World—or better, one of each country. The area of the basin of each river may be traced on the map, as before mentioned. Rivers have their sources in springs, snow melting on the tops of mountains, glaciers, lakes at the base of mountains, &c.

The importance of a river chiefly depends on the permanence of its *volume, depth, velocity, nature of channel, accessible entrance, &c.*

The *volume* depends chiefly on the extent of country drained by its affluence, which in temperate zones is generally lessened in summer and increased in winter; but, on the whole, the supply is pretty equable. In tropical countries, where the rain falls and snow melts at regular seasons, the rivers flow the country periodically. The *velocity* depends mainly on the slope and the nature of its channel, according to whether it is straight, deep, &c., or the reverse, and also upon the height of its source. The average slope is about 2 feet in a mile, or 1 in 2640. When it exceeds 1 in 250 it is unnavigable. A greater slope forms *rapids*, and a perpendicular descent a *cascade* or *cataract*.

The most remarkable waterfalls are :—

	Total Height.	
Orco Falls, at Monte Rosa (Alps)	2,400	feet.
Gavarnie, in the Pyrenees	1,400	,
Staubach, Switzerland	1,000	„
Maaneloan, Norway	940	„
Victoria Falls, on the Zambesi, Africa	100	„
Murchison Falls, on the Nile, Africa	120	„
Niagara Falls, on the River Niagara	160	„
Missouri (Great Falls)	75	„
Rinkan-fos, near Christiania	900	„

The *erosive* and transporting powers of a river depend nearly entirely on the rapidity of the currents—those, for instance, which run down the mountain sides, having a great slope and a swift current, will cut out deep *gorges* and *ravines* at the bottom. It has been calculated that a velocity of 3 inches per second will lift up fine clay; that 6 inches will lift fine sand: 8 inches, coarse sand; and 12 inches, gravel; while a velocity of 24 inches per second will roll along rounded pebbles an inch in diameter; and at three feet per second, angular stones of the size of an egg. A fine example of the erosive powers of rivers is exemplified in the River Niagara, where it is proved that the waters *at the falls* have cut back their passage about *seven miles*, forming a gorge 200 to 300 feet in height, and 600 to 1,200 feet in width, the average rate of recession being about 1 foot per annum. Another example may been seen in the *cañons*, such as, for instance, in the River Colorado, rising in the Rocky Mountains.

The amount of matter *transported* to the sea and other places by rivers is simply astounding. The slow rivers deposit a considerable portion in their course, as the Amazon, Ganges, &c., but the short and rapid ones carry it forward. The River Rhine, for example, carries past Bohn about 400 tons in one hour, or between three and four million tons in a year; and the Ganges, during the 122 days of rainy season, carries 339,413,760 tons past Ghazepoor, 500 miles from the sea—large islands having been made in its channel even during a man's lifetime.

The **quantity of material** carried down by rivers in suspension and solution respectively, may be determined thus :—

Firstly, the average quantity of water brought down by the river in a given time must be found. Then one unit of the quantity must be examined, and the quantity of matter found to have been deposited at the bottom of the vessel, added to the quantity of matter held in solution, and set at liberty by chemical means. This result multiplied by the number of units in the quantity brought down in the given time, gives the total quantity in that time.

Thus, for example, it has been calculated that the average quantity of water that flowed in the Thames, through Kingston, in wet and fine weather, is 1,250,000,000 gallons in 24 hours. A gallon of the water was examined, and found to contain 19 grains weight of mineral, principally carbonate of lime, which was held in *solution* by the water, besides the sediment. Hence, on a fine day, when hardly any mud is being carried down the Thames, past Kingston, no less than 3,364,286lb. weight of invisible matter is hurrying along the bottom.

To **guage the rate of sub-aerial denudation** from the above, we must calculate the quantity of rock which must have been worn away, to yield the quantity of mineral found. Thus, a ton of carbonate of lime makes up about a cubic yard of solid rock, and therefore, 3,364,286lbs. or 1,502 tons, are equal to 1,502 cubic yards, which is removed every day, or 548,230 cubic yards per year.

This matter, which is thus poured into the sea, is obtained from the river's *basin*, or whole area drained by the river, and *not* from it bed. Hence, by comparing this material with the area drained, we arrive at the conclusion that it is equal to the wearing away of the whole surface at the rate of $\frac{1}{830}$th part of an inch every year, or a waste of one foot in about ten thousand years.

The action of this river of ours is only an example on a small scale of what is going on in every part of the globe.

It has also been calculated, taking into account only the matter in suspension, *that the Ganges lowers its basin one foot in 2,358 years; the Mississippi in 6,000; the Hoang-Ho in 1,464; the Yangtse-Kiang in 2,700; the Rhone in 1,528; the Danube in 6,848, and the Po in 729 years. Taking the average of these, it appears "that atmospheric agencies are capable at present of lowering land surfaces at the rate of one foot in 3,000 years," and taking the land surface, and sea-bottom in the proportion of 145 to 452, we find that the ocean floors are silted up at the rate of one foot in 8,616 years.

If account had been taken of the matter held in *solution*, as well as in suspension, and also of the waste of coast-lines by the action of the sea, it is evident the time would have been considerably reduced, say roughly, one half, or about 4000 years for every foot of strata formed at the sea bottom, that is, supposing it were spread out uniformly. (See 85.)

The principal rock-constituents carried in suspension by rivers are quartz, or some very silicious mineral, and, in solution, common salt (sodic chloride), sulphates of lime and magnesia, carbonate of soda, and carbonate of lime. The substances held in solution still remain so, causing the saltness of the ocean (see 84), while those in suspension are deposited.

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* Notes on Physical Geography by Professor Haughton.

TABLE of the Principal RIVERS of the World, with their Sources, Length, Areas of Basins, and the Countries through which they chiefly run.

ARCTIC SYSTEM.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
Russia	Dwina	Great Plain	White Sea	696	106,400	Europe.
Russia	Petchora	Ural Mountains	Arctic Ocean	800	60,000	
Russia	Mesen	Central Russia	Arctic Ocean	—	30,600	
Siberia	Obi	Altai Mountains	Gulf of Obi........	2,306	1,500,000	Asia.
Siberia	Yenisei	Mongolia	Bay of Yenisei	2,800	1,100,000	
Siberia	Lena.............	West of Lake Baikal ..	Arctic Ocean	2,400	800,000	
Siberia	Kolyma	Stanovoi-Krebet Mountains	Arctic Ocean	800	200 000	
Hudson Bay Territory..	Saskatchewan	Rocky Mountains	Hudson Bay	1,300	600,000	North America.
Hudson Bay Territory..	Churchill	Northern Plains	Hudson Bay	700	90,000	
British America.......	Mackenzie	Rocky Mountains.....	Arctic Ocean	1,000	600,000	

94. Deltas.—The *detritus* transported by the rivers at their mouths has a tendency, especially in tideless or nearly tideless seas, to form more or less extensive flat plains at the point where the waters have lost their transporting powers, mostly commencing at the centre of the river's mouth, forming an island, which gradually widens and extends till a triangular space is formed by the deposit, the apex being directed up the river. The deltas of the Nile, Danube, Volga, Rhone, and Po are examples of those formed at the mouth of tideless rivers; but one of the most remarkable is the delta of the Ganges, the base of the triangle being 200 miles, and its side 220 miles. The delta of the Mississippi covers an area of 15,000 square miles, but is divided into innumerable lakes, marshes, &c. It has been calculated that this river carries down to its mouth 28,188,803,892 cubic feet of sediment per annum, or one cubic mile in less than 5¼ years.

95. River Systems.—The rivers of the world are all classed into four great systems. (1) *Arctic;* (2) *Atlantic;* (3) *Pacific;* (4) *Indian.* Thus, the Danube, Dneiper, &c., may be said to compose the Black Sea System; but the Black Sea is only an arm of the Mediterranean, which in its turn is only an inlet of the Atlantic; hence the Danube, Dneiper, &c., belong to the Atlantic. There are a few, however, not in communication with the ocean, losing themselves in sandy deserts, &c. These are termed *Continental Systems*, the most noted of which is that which empties itself in the Aral or Caspian Sea. It is estimated that the Atlantic drains 19,050,000 square miles; the Arctic, 7,500,000; the Pacific, 8,660,000; the Indian, 6,300,000; and Continental, 10,673,000

TABLE of the Principal RIVERS of the World, with their Sources, Length, Areas of Basins, and the Countries through which they chiefly run.

ARCTIC SYSTEM.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
Russia	Dwina	Great Plain	White Sea	656	106,400	Europe.
Russia	Petchora	Ural Mountains	Arctic Ocean	800	60,000	
Russia	Mesen	Central Russia	Arctic Ocean	—	30,600	
Siberia	Obi	Altai Mountains	Gulf of Obi	2,300	1,500,000	Asia.
Siberia	Yenisei	Mongolia	Bay of Yenisei	2,800	1,100,000	
Siberia	Lena	West of Lake Baikal	Arctic Ocean	2,400	800,000	
Siberia	Kolyma	Stanovoi-Krebet Mountains	Arctic Ocean	800	200 000	
Hudson Bay Territory	Saskatchewan	Rocky Mountains	Hudson Bay	1,300	600,000	North America.
Hudson Bay Territory	Churchill	Northern Plains	Hudson Bay	700	90,000	
British America	Mackenzie	Rocky Mountains	Arctic Ocean	1,000	600,000	

RIVERS—(*Continued*).—ATLANTIC SYSTEM.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
Netherlands, Prussia, &c.	Rhine	Central Alps	North Sea	800	87,000	Europe.
Austria and Turkey	Danube	South-West of Germany	Black Sea	1,725	234,000	
Prussia	Elbe	RiesengebirgeMountains	North Sea	600	58,500	
Russia	Dneiper	Centre of Russia	Black Sea	1,230	226,000	
Switzerland and France.	Rhone	Central Alps	Gulf of Lyons	645	70,000	
England	Thames	West of England	North Sea	250	6,000	
Africa	Senegal	Kong Mountains	Atlantic	1,000	—	Africa.
Nubia and Egypt	Nile	Victoria & Albert Nyanza	Mediterranean	3,760	—	
Central Africa	Niger	Victoria & Albert Nyanza	Gulf of Guinea	3,500	—	
South Africa	Orange River	Nieuvelt Mountains	Atlantic	1,000	—	
North America	Mississippi and Missouri	Rocky Mountains	Gulf of Mexico	4,382	1,500,000	North America.
Canada	St. Lawrence	West of Lake Superior	Gulf of St. Lawrence	2,150	300,000	
North America	Rio Grande del Norte	Rocky Mountains	Gulf of Mexico	1,800	250,000	
Brazil	Amazon	Andes of Peru	Atlantic	4,000	2,500,000	South America.
South America	San Francisco	South-East of Brazil	Atlantic	1,680	—	
Venezuela	Orinoco	Parimé Mountains	Atlantic	1,600	300,000	

RIVERS—*(Continued)*.—PACIFIC SYSTEM.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
China..................	Yang-tse-Kiang ..	Thibet	Yellow Sea........	3,600	700,000	Asia.
Manchouria	Amoor	North of Mongolia	Gulf of Tartary....	2,700	780,000	
China..................	Hoang-ho	Thibet	Yellow Sea	2,400	720,000	
India	Mekong	Borders of China	Chinese Sea	1,700	—	
India	Menam	Mountains of Yunnan..	Gulf of Siam	800	—	
North America	Youcon	Rocky Mountains......	Behring Sea	1,200	—	North America.
North America	Columbia	Rocky Mountains.....	Pacific Ocean......	1,200	270,000	
North America	Colorado	Rocky Mountains......	Gulf of California..	700	—	

RIVERS—(*Continued*).—INDIAN OCEAN.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
Asiatic Turkey	Euphrates	Armenian Mountains..	Persian Gulf	1,800	260,000	Asia.
Hindostan	Indus	Thibet	Arabian Sea	1,800	400,000	
Hindostan	Ganges........	Himalayas	Bay of Bengal	1,550	400,000	
Assam	Brahmaputra	Thibet	Bay of Bengal	1,800	220,000	
Hindostan	Krishna	Ghauts...............	Bay of Bengal	700	—	
Burmah	Irrawady	Borders of Thibet	Gulf of Martaban..	1,200	440,000	
Hindostan	Godavery	Ghauts...............	Bay of Bengal	750	—	
Asiatic Turkey	Tigris	Armenian Mountains..	Euphrates	1,150	—	
Burmah...............	Saluen	Thibet	Martaban	1,020	—	
Africa...............	Zambesi	Lake Dilolo	Mosambique Chan.	2,400	600,000	

RIVERS—(*Continued*).—CONTINENTAL SYSTEM.

Country.	River.	Source.	Mouth.	Length in Miles.	Drainage Basin in Square Miles.	
Russia	Volga	Valdai Hills	Caspian Sea	2,400	520,000	Europe.
Russia	Ural	Ural Mountains	Caspian Sea	1,040	80,000	
Georgia	Koor	Plateau of Armenia	Caspian Sea	560	2,000	
Turkestan	Sir-daria	Thian-shan Mountains	Sea of Aral	1,200	350,000	Asia.
Turkestan	Amoo, or Oxus	Lake Sir-i-kol	Sea of Aral	1,300	250,000	
Afghanistan	Helmund	N E. of Afghanistan	Lake Amoon	650	—	
Palestine	Jordan	Mount Lebanon	Dead Sea	200	—	

96. Lakes are large collections of water formed in the depressions of the earth's surface. They are generally classed into four or five kinds, but belonging to two natural divisions, viz., (1) Those which once formed part of the sea but have been cut off by the elevation of a portion of the sea bed, as the Caspian and Aral Seas ; and (2) Depressions in the surface of the land, which receive a portion of the drainage, as the great lakes of America, and most others. (*a*) Lakes that both receive and discharge rivers, which are in most cases only expansions of the stream. Their water is *always* fresh, examples of which are the great American and African lakes. These lakes are sometimes called lakes of *transmission*. (*b*) Lakes which receive no streams but discharge water by their own, the supply being kept up by springs. They are mostly small and fresh. The source of the Volga is a lake of this description in the Valdai Hills. They are termed lakes of *emission*. (*c*) Those that receive water but have no visible outlet, the waste by evaporation being supposed to be equal to the supply. The lakes of this description are generally large, and either salt or brackish, such as the Caspian, Aral, and Dead Seas, Lakes Balkash, Van, &c. (*d*) Those which neither receive rivers nor have any visible outlets. They are generally of small size, and occupy craters of extinct volcanoes, as Lake Albano, near Rome.

Lakes may be also classed as—(1) *Mountain* Lakes, in deep glens and ravines scooped out of the flanks of the mountains, as in Britain and Italy ; and (2) *Lakes of the Plain*, in low levels, often marshy and flat around their border, as in Russia.

97. Origin of Lakes.—The accumulating knowledge of late years on this subject has gone to prove that great lakes were originally salt, then brackish, and finally fresh in their water, and the presence of living things, as blind crustaceans, and others that have eyes also, in them, shows that they have not been filled up with solid matter since they were originally salt, and formed part of the sea. Owing to the upheavals during the slow formation of mountain chains, the depressions in the old sea-floor are now land lakes, hundreds and even thousands of feet above their former level.

Sometimes lakes have been formed in valleys, in mountains along which rivers ran, becoming blocked up. Thus the earth would be sculptured by atmospheric agencies—frost, running water, and glaciers : then during some one of the many great movements of the crust, upheaval took place in the course of a valley, and the water was dammed up.

Again the smaller lakes of the Alps have in many cases been scooped out by glacial action—but no doubt many large lakes owe their origin to volcanic energy. Undermining and falling in of the ocean floor by volcanic matter being abstracted to make volcanic hills close by is a true cause of lake formation on the grandest scale.

98. Distribution and Areas of Lakes.—Lakes have a peculiar tendency to occur in groups. For instance, in North America there is the series consisting of Lakes Superior, 32,000 square miles; Huron, 24,000; Michigan, 20,000; Erie, 9,600; Ontario, 6,300; the Great Bear, 19,000; Great Slave, 12,000; Winnipeg, 9,000; Winnipegosis, 3,000; Athabasca, 3,000; Manitoba, 2,100; Deer, 2,400; Wollaston, 1,900. In Asia they occur as three distinct groups. Many of the lakes in this country are salt or brackish, the chief of which are the Caspian (inland sea); Aral, 26,000 square miles; Balkash, 7,000; Urumiah, 1,800 (26·24 per cent saline matter); Van, 1,600; Tongrinor, 1,800; Koko-nor, 1,500; Lob, 1,300; Dead Sea, &c. Of the *fresh water* lakes the principal are Baikal (Holy Sea of the Russians) in Siberian Tartary, 14,800 square miles; Tong-Ting, 2,000; Bookanor, in Thibet, 1,000; Zaizan, 1,000, &c. In Africa the principal are the Victoria and Albert Nyanza, Tanganyika, Dembea (1,400). In Europe the principal lakes occur as a group in Finland and Russia. They are Ladoga, 6,633 square miles; Onega, 3,280; Saima, 2,000; Peipus, 1,250; Enara, 1,200—which all occur in a circumscribed area. Others occur in Sweden, namely, Wener, 2,130 square miles; Wetter, 840; Maelar, 760, &c. Small lakes occur abundantly in the mountain regions and are remarkable for their lovely scenery, examples of which are our own—namely, those in Scotland, the north of England, the south of Ireland—and the much greater ones of the Alps. The chief of the Alpine lakes are Geneva, 240 square miles; Constance, 228; Garda, 182; Maggiore, 150.

Neufchatel, 114 square miles; Lucerne, 98 square miles; Zurich, 74 square miles, &c. Those in the British Isles are Lough Neagh, 150 square miles; Corrib, 63 square miles; Erne, 56 square miles, &c., in Ireland. Loch Lomond, 40 square miles, &c., in Scotland. Windermere, 10 square miles, &c., in the Cumbrian Hills.

The most elevated lake is Sir-i-kol, 15,600 feet, in Central Asia; Tuz-Gul, in Asia Minor, the saltest known, containing 32 per cent of saline matter; Urumiah, 26·24 per cent; the Dead Sea, 24 per cent; and Lake Elton, situated in the Steppe, 70 miles E. of the Volga.

The *uses* of lakes are (1) Acting as *regulators* to rivers, and preventing the too rapid flow of the waters during excessive rainfalls; (2) Acting as settling ponds for the water to purify in; (3) Serving to temper the climate, especially when occurring in the central part of the continent; (4) They supply mists, rains, dews, &c., to the surrounding country, by evaporation from their surface.

THE ATMOSPHERE.

99. Composition of the Atmosphere.—The envelope of gaseous matter which surrounds our earth is called the *atmosphere*,* or *atmospheric* air. It is a mixture (not a chemical compound, each gas still possessing its own peculiar property) of oxygen and nitrogen, contaminated with a very small, but variable, proportion of carbonic acid and water in a state of vapour. It consists by weight of one atom of oxygen to two of nitrogen, and by volume of one part oxygen to four nitrogen, nearly; or, more exactly, its percentage is 79·5 nitrogen (N), 20 oxygen (O), ·45 aqueous vapour (H_2O), and ·05 carbonic acid (CO_2).

Its composition may be proved thus: Take a small piece of dry phosphorus (P), as big as a pea, and float it on some water on a dish. Place a bell-jar open at the bottom, and furnished with a neck and cork at the top. Light the phosphorus with a warm piece of wire passed through the neck, after which, insert the cork immediately. The phosphorus will burn, combining with the oxygen in the air in the bell, forming phosphoric acid (P_2O_5), which fills the jar in the form of white fumes. After a little time it goes out, although not all burnt. The white fumes gradually disappear, and instead of the bell being full of air as before, it contains water, which rises slowly till it occupies ⅕ of the space originally filled with air. The fumes of P_2O_5 having become dissolved in the H_2O, there remains in the jar an invisible gas, in volume about ⅘ of that of the air which the bell-jar originally contained.

If the cork is taken out of the bell-jar, and a burning taper plunged into this gas, it goes out—thus proving that this gas which remains is not combustible, neither will it support combustion. This gas is nitrogen. The oxygen had all been consumed by the phosphorus, or in other words it had united with that element. We thus see that air contains about one-fourth oxygen, and four-fifths nitrogen, and also that oxygen is the great supporter of combustion and nitrogen not.

That air is a mixture and not a chemical compound may also be proved from the fact that the proportions of each element in air do do not always appear the same, but vary slightly. When substances chemically combine they always do so in certain fixed and definite proportions.

Though nitrogen forms by far the greater part of the air, we see oxygen is the most important. Without it no animal could live or fire burn. It is this gas that purifies the blood, keeps up its natural warmth, and is the supporter of flame. Nitrogen may be termed the agent by which oxygen is held in check by diluting it.

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* *Atmos*, vapour. *Sphaira*, a sphere.

The air in its diluted state forms the food upon which the vitality of both animals and plants is sustained ; but, while it is inhaled by both in breathing, animals exhale carbonic acid, and carbonic acid is inhaled and assimilated by plants, which in their turn exhale oxygen, thereby keeping up the equilibrium or balance.

Another source of CO_2 in the atmosphere is *combustion.* All ordinary combustibles contain the elements H and C in combination. When the substance burns, the H unites with the O in the air forming H_2O, and the C combining with O forms CO_2.*

From the above we see that air contains as *elements,* nitrogen, oxygen, hydrogen, and carbon ; and as *compounds,* water, carbonic, dioxide. To these we may add carburetted hydrogen, sulphuretted hydrogen, sulphurous acid, ammonia, and nitric acid, slight traces of which are generally to be found. Though, as above stated, the air is not a chemical compound, but simply a mixture, yet it has much permanence of character, its two chief elements being found nearly in the same proportion in all climates and altitudes, and according to the *law of diffusion of gases,* all the gases thoroughly mix or diffuse into one another. If it were not for this we should have the heavier gas CO_2 at the bottom, rendering the air unfit for animal life.

100. Pressure of the Atmosphere.—Air, like other perfect gas, exerts an expansive force directly proportional to its density. This force is measured by means of the barometer, the pressure per square inch being equal in weight to a column of mercury supported in a barometric tube, the area of a section of which is one square inch, the mean height of which at the level of the sea is 30 inches, and its weight about 14¾lb. (14·7304) avoirdupois, which is, therefore, the *mean pressure* of the atmosphere per square inch. The pressure and density of the air are regulated by the following law : *At the same temperature* the *elastic* forces, or pressure, of two portions of air are in direct proportion to the densities, or in inverse proportion to the spaces occupied by these portions. The atmosphere is much denser near the level of the sea than at some distance above it, owing to its being confined to the surface of the earth by gravitation ; or, in other words, being pressed down by the weight of that which is above. The density rapidly decreases the higher we ascend. For instance, at an elevation of three miles it is one-half the density it is at the earth's surface ; at six miles it is one-fourth, at nine miles one-eighth, at twelve miles one-sixteenth, and so on, the *density decreasing in geometrical progression as the height increases in arithmetical progression.*

The pressure of the atmosphere is exerted on all substances, both *internally* and *externally.* The body of a man of ordinary stature has an area of about 2,000 cubic inches, hence the pressure on the body will be 14·7304 × 2,000 = 29,460·8lb. But how is it, it may be asked, that this immense weight does not crush the man? The answer is that the air *within* the body and its pores counterbalances the weight of the *external* air. On every square mile the pressure, or weight, is 26,345,088 tons; so that the total pressure on the earth's surface is 5,189,982,336 million tons.

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* It is now taken for granted the student understands the chemical symbols.

101. Height and Temperature of the Atmosphere.—From the law given above regarding the density of the air the higher we ascend, it is evident that the greater part of the atmosphere is always within 32 miles of the surface of the earth, but how far it really extends is extremely uncertain, though it may with safety be affirmed to reach the height of 45 miles, where it is about 25,000 times *rarer* than at the level of the sea. Even at the height of six miles the air is so rare that man can hardly breathe. Though the greater part of the atmosphere is always within 30 miles or so from the surface of the earth, yet it is very probable that even at the height of 250 miles a very rare atmosphere exists.

Not only does the pressure decrease the higher we ascend, but also the *temperature*, though not at such a constant rate. The atmosphere being the medium through which the sun's heat is conveyed to and from the earth, the lower and denser strata or layers absorb the greatest amount, and are necessarily the warmer. In ascending mountains the decrease of temperature averages about 1° F. for every 300 feet. The averages, according to Mr. Glaisher, in his balloon ascents made in this country, when the sky was partially clear, are as under :—

Elevation in feet.	Number of feet corresponding to a diminution of 1° F.
0 to 1,000	140
1,000 „ 2,000	190
2,000 „ 3,000	220
3,000 „ 4,000	290
4,000 „ 5,000	370
5,000 „ 10,000	370
10,000 „ 20,000	470
20,000 „ 30,000	820

102. Weight of Air.—That air has weight may be easily proved in the following manner: Take a vessel measuring 10 inches in length, breadth, and height, and provided with a stop-cock. Let its weight be accurately determined. Exhaust the air from it by means of an air pump, turning the stop-cock immediately; then, on weighing again, it will be found to have lost 310 grains, which is evidently the weight of the air contained in the vessel—namely,

$10^3 = 1,000$ cubic inches; or 1 cubic foot of dry air, at 60° F., weighs about 535 grains.

103. The Barometer is an instrument to measure the weight or pressure of the atmosphere, and thereby to indicate the variations of the weather. It consists of a cylinder or tube, from which the air has been exhausted, closed at one end, the open end being inserted in a cup of mercury, on which the pressure of the atmosphere is exerted, forcing the mercury up the tube (there being no pressure there) until it reaches the height of 29·94 inches, when the weight of the column of mercury equals the pressure or weight of the atmosphere on the surface outside the tube. Supposing water to be used instead of mercury, the column would be about 33·8 feet, or 13·568 times the height of the mercury, through the latter being that many times heavier than water. As the air varies in weight or pressure it is evident that it will influence the mercury in the tube, which will rise and fall in exact proportion with the pressure. The column of mercury in the barometer undergoes several regular variations in the course of the day, which are termed *horary variations.* According to Humboldt, the maximum elevation at the equator takes place about nine o'clock in the morning, after which hour it becomes less until about four or half-past in the afternoon, attaining its minimum. It again ascends until eleven at night, when it attains its second maximum, once more descends till four, reaching its second minimum, and then starts on its journey back until nine. It has also been noticed that the elevation of the mercury at noon corresponds almost exactly with the mean diurnal height. These variations are due to the action of the sun's rays upon the air and vapour atmosphere. The mean pressure of the atmosphere is also subject to an annual oscillation, the amount of which, except for some particular places, has not yet been ascertained.

104. The Aneroid Barometer.—A compendious and portable instrument, capable of showing even approximately the barometric changes, had long been a desideratum, until the recent invention of the aneroid barometer. This instrument consists of an exhausted metallic chamber, one side of which is sufficiently thin to yield slightly by its elasticity to the pressure of the atmosphere, the compression being proportional to the compressing force. The short arm of a lever acts against this side, the other arm being connected with an index. The longer arm being very much longer than the other one, very minute movements of the elastic lamina of metal, corresponding to the changes of atmospheric pressure, are indicated by much larger movements of the index, which traverses a graduated dial. Thus, when the pressure of the air increases, the lamina is pressed inwards. When it diminishes, the elasticity of the side brings it back to its original position. Although very convenient for approximately measuring the varying pressure of the atmosphere, and for a short time fairly accurate, for scientific and exact indications it is not to be relied on.

105. Self-registering Barometers have been so constructed as to record their own variations by some automatic process. Various mechanical arrangements have been devised, in which the gravity of the displaced column of mercury is made to act upon a pencil, which, moving uniformly in its own plane, marks a sheet of paper. The movements of the pencil, corresponding to those of the column of *Hg.* are in a direction perpendicular to that of the paper, so that by the combined movements of the pencil and paper, an irregular line or curve is traced, of which the abscissæ represent time, and the ordinates the corresponding variations. Another method of registration is by the aid of photography.

GENERAL RULES PROGNOSTICATING CHANGES IN THE WEATHER BY MEANS OF THE BAROMETER.

106. The following rules, which are without doubt the best yet given by any authority, are those of Patrick. (1) The rising of the mercury presages, in general, fair weather, and its falling the contrary, as rain, snow, high winds, and storms. (2) In very hot weather the falling of the mercury indicates thunder. (3) In winter the rising presages frost; and in frosty weather, if the mercury falls three or four divisions (tenth of an inch) there will be snow. (4) When foul weather happens soon after the falling of the mercury, expect but little of it; and, on the other hand, little fair weather may be expected when it becomes quickly fair after the rising of the mercury. (5) In foul weather, when the mercury rises much and high, and so continues for two or three days before the foul weather has gone away, then a continuance of fair weather may be expected to follow. (6) In fair weather, when the mercury falls much and low, and thus continues for two or three days before the rain comes, then a great deal of wet may be expected to follow. (7) The unsettled motion, or frequent rising and falling, of the mercury denotes changeable weather. (8) The chords on the scale are not so strictly to be observed as the rising and falling of the mercury, for if it stands at much rain and then rises to changeable, it presages fair weather, though not to continue so long as though the mercury had risen higher; and so, on the contrary, if the mercury stands at fair and then falls to changeable it presages foul weather, though not so much as if it had sunk lower.

107. The Barometer is also used for measuring the heights of mountains or the height of the country above the sea level, &c., though for this purpose very accurate instruments are required, such as Roughton's portable ones. As we ascend from the level surface of the earth the column of atmosphere pressing on the mercury becomes lighter by the removal of the subjacent stratum, hence the fluid falls in the tube of the barometer. For ordinary purposes the following very simple rule by Sir John Leslie is sufficiently accurate:—Mark the height of the mercury in the barometer at the bottom of the height to be measured, and also at the top; then, as the sum of the heights of the mercury at the bottom and top stations is to their difference so is 52,000 to the height to be measured in feet. Another rough rule is—Multiply the difference of the logarithms of the barometric heights by 1,000, and the difference of the levels will be obtained in fathoms. Generally, for every inch that the mercury falls we may reckon 992 feet. The reverse to finding the heights of mountains, &c.—namely, estimating the depth of pits—may be found with equal facility by the aid of the barometer. For instance, at a depth of 15,000 feet it stood at 32·28 inches, while one at the surface stood at 30·518.

108. The Atmosphere in Relation with Light.—The atmosphere is the medium by which the sun's heat and light are conveyed to this earth. Each ray proceeding from the sun consists of two distinct parts—the one producing light, the other heat. Heat and light are alike indispensable to plants and animals, and are so *reflected* (turned back) and *diffused* by the atmosphere as to become most available to vegetable and animal life. White light is a combination of red, orange, yellow, green, blue, indigo, and violet rays. Vapour, whether in the atmosphere or sea, absorbs all the coloured rays except blue; hence the colour of the ocean and sky, the sky always appearing of a much darker color than the tops of high mountains. Not only is light *absorbed* by the atmosphere, but *reflected*, *refracted*, and *diffused* or *dispersed*. As soon as the rays meet the earth's atmosphere a portion is *reflected*, the remaining portion being *refracted* or bent on entering the air. Some of the portions, in their journey to the earth, are *absorbed*, while others are *dispersed*, thereby causing each ray to illuminate a much greater space than if there had been no atmosphere to have disturbed its course, so that valleys and surfaces not directly exposed to the sun are lighted. If the rays fall vertically, only eight out of every ten reach the earth's surface. The greater the angle of inclination the greater the number absorbed. When the sun is rising or setting we can gaze on it with ease, owing to this; as for instance, when it is horizontal, only five rays out of every 10,000 reach the eye of the observer. It is to the refraction of the sun that we owe that dim light called *twilight*, as when the sun is from 15° to 20° *below* the horizon the rays strike the atmosphere, or clouds, and are *bent down* *towards the earth,* producing a little light. Within the tropics the sun sets more perpendicularly, hence speedily. In higher latitudes it sets more obliquely, taking a longer time to reach 20°, and thereby causing the longer twilight of those regions.

109.—Rainbows.—The semi-circular band or arc, composed of different colours, appearing upon the clouds during the occurrence of rain in sunshine, which we term a rainbow, is caused by the *refraction* and *reflection* of the solar rays in the drops of falling rain. It can be only witnessed when the sun is in a certain altitude above the horizon—namely, 42° 30′—and when the rain is falling between the observer and the part of the sky opposite the sun. The same phenomenon may be witnessed in the case of the spray of *cascades* and *waterfalls.*

There are sometimes two *bows* to be seen, namely, when the light is intense, or being sufficiently low in the sky, a second is formed on the *outside* of the first or *primary* one, by the solar ray entering near the bottom of the drops. The rays undergo two refractions and two reflections in passing through the drop. The colours in the second or secondary one always appear fainter that in the first.

THE MIRAGE.—The unusual elevation of islands, ships, &c., above the surface of the sea, is due to refraction, and occurs when the atmosphere is warmer than the surface of the sea.

110. Sound is produced by causing the *air*, or any elastic body, to assume a vibratory motion. The vibrations produce *undulations*, which are propagated by the air, or transmitted by some other elastic medium. Hence sound, like heat and light, is *motion.* The more rapid the vibrations of the medium, the louder the sound. The velocity of propagation, or the speed with which a sound-wave travels, depends upon the elasticity and density combined of the medium through which it passes. Sound, in travelling through air at the ordinary pressure and temperature, travels at the rate of about 1,100 feet per second. The knowledge of this fact is useful to enable anyone to tell the distance at which a clap of thunder originated. Thus, supposing a flash of lightning to be seen eleven seconds before its accompanying thunderclap is heard, we know that the distance from the observer to the place where the clap originated must be 1,100 × 11 = 12,100, or about 2¼ miles. This is not quite correct, as the interval is really the difference in time it takes sound and light to travel from the place where the lightning occurred; but as light travels so much faster than sound, we may neglect it without any sensible error, as in the above case the light would not take one-fifteenth of a second to travel the distance.

111. Temperature is the *actual state* of a body at any moment, determined by a comparison of its magnitude with the heat to which it is exposed. A *change in temperature* is a change in magnitude which the body suffers in the *heat* to which it is exposed. The *intensity* of heat is measured by an instrument termed a *thermometer.*[*] This consists of a glass tube, hermetically sealed at one end, with a bulb at the other containing mercury, which was introduced at a certain temperature through the open end, then heated to drive off all the air, and afterwards sealed that no air could get in. This tube is generally fixed to a hard piece of wood or ivory, on which a scale is engraved. This scale has been previously obtained by immersing the thermometer in an upright position in melted snow or pounded ice for about half an hour, until the mercury has ceased to fall, the height of which is then marked on the tube. This is the *freezing point.* The *boiling point* is obtained by placing the thermometer vertically in the steam of pure water until the mercury has ceased to rise, when a mark is instantly made. The distance between these two marks is then divided either into 212, 100, or 80 divisions, according whether it is to be a Fahrenheit, Centigrade, or Reaumur. The reason mercury is chiefly used in the thermometer is because of its nearly uniform expansibility under a considerable range of temperature. When very low temperatures are investigated coloured alcohol is used, it being more able to resist congelation than mercury or any other known fluid.

When the temperature of bodies is raised they, with few exceptions, increase in bulk, this increase arising from the repulsive power of heat. Gaseous bodies expand equally for equal increments of temperature. Thus 1,000 parts of air at the freezing point (32° F.) are increased to 1,365 at the boiling point (212° F.) Mercury in the same range increases from 1 to 1 0019, water to 1·0046, and alcohol to 1·0011. It is this expansion and contraction of the mercury or alcohol in the thermometers which measures the increase and decrease in temperature.

There are three kinds of graduation. That of Fahrenheit takes 0° (zero), 32° below freezing point, the boiling point of water being 212°. In the Centigrade the freezing point is 0°, and the boiling point of water 100°. In Reaumur they are respectively 0° and 80°. In each below 0° is counted with the *minus* sign.

Rules.—To convert the degrees of Fahrenheit into those of Reaumur: *Multiply the number of degrees, less* 32, *by* 4, *and divide by* 9. To convert the degrees of Reaumur into those of Fahrenheit: *Multiply the given temperature by* 9, *divide by* 4, *and add* 32. To convert the degrees of Fahrenheit into their Centigrade equivalent: *Multiply the number of degrees, less* 32, *by* 5, *and divide by* 9. To convert Centigrade degrees into those of Fahrenheit : *Multiply by* 9, *divide by* 5, *and add* 32.

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[*] *Thermo*, heat. *Metron*, a measure.

112. **The Minimum Thermometer** is employed for registering lowest temperatures. It is usually an alcohol thermometer, having its tube horizontal, and a glass float, which is carried backwards when the temperature falls, and is left behind when it rises.

Maximum Thermometers.—There are two or three distinct kinds. The most common is that which consists of a mercury thermometer, with tube horizontal, and containing a small stick of steel, called the index, which is pushed forward by the Hg. when the temperature rises, and is not drawn back when it falls.

113. **Heat.**—As the atmosphere interferes with the light-producing rays, so it does with the rays which produce heat. Though the air itself is transparent to heat, *the moisture which it contains is not*, being opaque to it, preventing a large quantity of it from passing through to the earth. For it must be remembered, that whatever the temperature of the air, it is constantly receiving moisture from the surface of the land and water, thereby causing what we might nearly term a second atmosphere. (See "Vapour.") The heat that falls on the surface of the earth is partly absorbed and partly radiated into the atmosphere. The air through which the heat passes is not sensibly heated by the passing of the rays of heat, but by *conduction*—namely, the warmth of the heated earth is communicated to the air, the air in its turn communicates heat to the overlying stratum of air, and so on. Hence each layer of the atmosphere must be cooler than the underlying one, as it would be impossible for the earth to make the nearest layer of air as hot as itself, and for the nearest layer to make the next stratum of the same heat as itself, &c. (For "Average Decrease of Temperature" see 101.)

114. **Winds, or Air in Motion.**—Wind is air in motion. As there are currents in the ocean, so there are currents in the atmosphere, the cause of which is the unequal distribution of pressure in the atmosphere, owing to the unequal distribution of heat and vapour. When any portion of the air is heated it expands, and loses its specific gravity, thereby causing it to ascend, whereupon a current of colder air rushes in to supply the vacancy and to restore equilibrium. In this way winds are produced. One of the most notable characteristics of winds is their velocity, which varies from a few miles to more than a hundred miles an hour—that is, from the gentlest zephyr to the most violent hurricane. When it is moving at the speed of 7 miles an hour it is called a *gentle air;* of 14, a *light breeze;* of 21, a *good sailing breeze;* of 41, a *gale;* of 61, a *heavy storm;* of 81, a *tempest;* of 92, a *hurricane;* and of 100, a *violent hurricane*, with a force sufficient to blow down buildings, tear up trees, &c.

115. The Force of the Wind is measured by the **Anemometer.** This instrument consists essentially of four hemispherical cups fixed to the ends of two horizontal cross rods, which are fixed to a vertical axis about which they can turn freely. These cups have their diametrical planes opposite to a passing current of air; so that the velocity of the wind causes the arms to rotate. A simple arrangement of wheels and screws is appended to the instrument, which, by means of two indices, shows on inspection the space traversed by the wind.

Another method of determining the velocity is that of Professor Leslie, who having found that the cooling power of wind is proportional to its velocity, determined that velocity from the formula $V = 1 - \frac{9T}{2\,t}$ (by means of a spirit of wine thermometer) where V = velocity of wind in miles per hour, T the time in which the number of degrees to which, by the application of heat, it has been raised above the degree at which it previously stood, and *t* the time in which the top of the alcohol, when exposed to the action of the wind and raised as before, descends through an equal number of degrees.

The Direction of the Wind is indicated by the **Anemoscope,** which consists of a vane turned by the wind, and whose motion is communicated to the index of a dial.

From continued observations, it is shown that the winds always blow towards the place of the lowest barometer reading, or lowest pressure. Hence by knowing the barometer readings over a large area of country, an observer is enabled to trace the march of the storm, and by means of the telegraph give warnings to those places where the storm may be expected.

The following table will give an idea of the relation between the *velocity, force,* and *character* of the wind more minutely :—

Velocity in miles per hour.	Force in lb. Avoid.* per square foot.	Common name.
1	·005	Breath of air.
5	·123	Gentle air.
10	·496	Brisk wind.
15	1·11	Light breeze.
20	1·98	Brisk breeze.
30	4·5	High wind.
35	6	Gale.
40	7·9	Strong gale.
50	12·5	Storm.
60	17·75	Great storm.
80	31·5	Hurricane or tempest,
100	49·5	Violent hurricane.

Winds are classified into three classes, viz., *constant, periodical,* and *variable;* but, in whatever class or character they occur, they are important agents in the modification and production of climate. The most remarkable of the *constant* or *permanent* air currents are the *trade winds* and the *polar winds.*

116. The Trade Winds, so called from their influence on the trade and commerce of the world, are those which prevail within the tropics, extending from the parallel of about 30° north and south nearly to the equator, forming two zones of perpetual winds, the one in the Northern Hemisphere blowing from the *north-east,* and that in the Southern Hemisphere from the *south-east.* This zone, being the highest in temperature, causes the heated or rarified air to ascend and flow off as *upper currents,* travelling towards the poles, whilst the colder air from the temperate zones rushes in as *under currents* to supply its place. If it were not for the earth's rotation on its axis this colder air would come exactly from the north and south; but owing to the earth's revolution from west to east, and that places near the equator move at a much more rapid rate than those in the temperate or arctic regions, the air current cannot acquire all at once the velocity of that part of the earth over which it is advancing, hence it is necessarily left somewhat in the rear; and as it is struck by the objects in that zone with a certain force it is deflected in a westerly direction, thereby becoming a north-east wind in the Northern Hemisphere and a south-east wind in the Southern.

This deflection is caused by the two motions which influence the air, viz., (1) a northerly or southerly motion, caused by its tendency to rush to the equator to supply the place vacated by the heated air, and (2) an easterly motion resulting from the earth's rotation. But the air will not obey either motions or forces, taking an intermediate course, namely, in the direction of a diagonal of a parallelogram, the sides of which represent the magnitude and direction of the two forces. (See 7.)

In the Pacific the north-east trade wind may be said to range between the 9th and 25th degrees of north latitude, and the south-east one ranges between the 10th and 21st of south latitude. In the Atlantic the former is comprised between the 30th and 8th degrees of north latitude, and the latter within the 3rd of north and the 28th of south latitude. These limits, however, vary, advancing with the sun. Thus at the summer solstice the region of the winds is entirely carried north of the equator, and at the winter solstice it is carried considerably south, but not entirely passing the equator. The reason it goes farther north than south is owing to the greater quantity of land in the Northern Hemisphere. Of the two the trade wind in the Southern Hemisphere is the stronger and more constant. Their regular rate is from 10 to 20 miles per hour, but on approaching the continents their courses are interrupted by the unequal heating of the land and water surfaces. Hence within these coast areas, instead of currents being perennial, they assume a periodical character, and as they approach the equator of temperature their currents begin to abate, thereby producing the region or *belt of calms*, as they are termed. There are also other belts of calms, each formed where the winds cross, as the *belt of calms of Cancer* (sometimes called the *horse latitudes*) and the *belt of calms of Capricorn*, where the trades and anti-trades, as these westerly winds are called, interchange.

117. Periodical Winds.—The most important of this description are—

(1) The *monsoons*, which are modifications of the trade winds (or trades as they are called), being due to the presence of vast masses of territory. They are termed *monsoons*, or *season winds*, because they change their course with the *seasons*, blowing from one part of the earth for one-half of the year, and from the opposite part for the other half. From April to October they blow from the south-west, and from October to April from the north-east. They prevail chiefly in the Indian Ocean, extending to the north and east of Astralia into about 14° west longitude. When the sun is north of the equator, the large continents of India and China are heated to a very great extent, heating the surrounding air, which rises, and the south-east trade rushes in to fill the vacant space; but owing to the rotation of the earth and other local causes, it is deflected, becoming the south-west, south, south-east, or east monsoon on different parts of the coast. Similarly, when the sun journeys on to the Southern Hemisphere, the wind follows, and causes what is called the south-east monsoon, blowing from October to April, though this is really the ordinary north-east trade wind. At the changes from one to the other in April or October—a period known among mariners as the *breaking up of the monsoons*—furious storms of wind, rain, and thunder occur, owing to the two opposite air currents contending for the mastery. There are other parts in which the monsoons occur, as on the West Coast of Africa, the coast of Brazil, the coast of America from California to about 45° south latitude, &c.

(2) *Land and Sea Breezes* prevail on almost every seaboard, but more particularly in the tropics, where they occur regularly. The *land breeze* sets in during the night, and the sea breeze during the day. They owe their origin to the unequal temperature of sea and land by night and day. Thus, during the night the land loses its

heat by radiation more rapidly than the sea; hence the cool air from the land flows to the sea, to take the place of the warmer air, and thus forms the *land breeze*. In the daytime just the opposite occurs, as the cool air flows from the sea towards the land and creates the *sea breeze*. To many islands they are of great importance, as by their influence they are kept cool and inhabitable.

118. Variable Winds.—In addition to the winds above enumerated there are others which are very variable, still they are obedient to law and law-directed forces; but these forces being so complicated they are not, comparatively speaking, so well understood. There are two winds in the Northern Hemisphere which may be considered the prevailing winds—namely, that of the north-east, being the cold polar one on its journey to the equator, and that of the south-west, being the warm equatorial currents hurrying to the poles; and similar in the Southern Hemisphere. In our own country we often notice some winds are wet, some dry, some hot, and some cold. Thus for instance, the south-west wind blows across the Atlantic, coming from warm regions, so that it takes up a great amount of moisture, which it precipitates when it reaches cooler regions, as our shores for instance. On the other hand, the east wind comes to us across the vast plains of Northern Germany. In the latter part of the spring those plains are very cold, and, therefore, the winds are found to be very severe. They do not bring rain, because their track has been over a vast area of land. Again, south-west winds having passed over the hot sandy deserts of Africa are warm and dry, till their passage over the Mediterranean Sea and English Channel, where they absorb a large amount of moisture.

All other winds are local, depending on local circumstances, a few of which we will just briefly mention.

Hot Winds.—The chief of these are those that originate in the Great Desert of Sahara, and they go by several names, but are generally called the *simoom.*[*] In Turkey they are called *samiel;* in Egypt *khansin* (fifty); in Italy, *sirocco;* in Spain, the *solano;* and in Guinea and Senegambia, *harmattan.* The *simoom* is an intensely hot, suffocating wind, laden with fine particles of sand, often causing destruction to the whole caravan of men and animals. The only way to escape its effects is to lie prostrate on the ground, with the face buried in the sand, till the violence of the blast is passed. The *föhn* is the name given to the hot winds that occasionally blow over Switzerland.

There are other winds just the reverse of these—namely, cold piercing ones—such as the *puna, pampero, bora, mistral,* &c. The *puna* is so called from originating in the upland of Puna, sweeping over the Plateau of Peru for about one-third of the year. The *pampero* is a violent west wind, which passes over the pampas of Buenos Ayres. The *bora*, blowing north-east from the Alps, in Istria and Dalmatia, is at times very violent indeed, overturning both horses and men at the plough. The *mistral* is a violent north-west wind, blowing down the Gulf of Lyons, and felt chiefly in the south-east of France. The *etesian** *winds* are those which prevail very much in early summer all over Europe.

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[*] Arabic *hot, poisonous.*

119. **Storms** are sudden and violent commotions of the atmosphere. All great storms are found to partake of a circular motion, though the diameter or whirl is often hundreds of miles in extent. Those needed to be mentioned here are *cyclones*, *typhoons*, *tornadoes*, *hurricanes*, and *whirlwinds*.

Cyclone is the name applied by navigators to those rotatory hurricanes which most frequently occur between the equator and the tropics, and near the calms of Cancer and Capricorn. They sweep round and round with a progressive motion, describing a curve, rotating in both hemispheres in a contrary direction to the sun. In different regions they are known as *tornadoes*, *whirlwinds*, *typhoons*, and *hurricanes*, being called *hurricanes* or *tornadoes* in the West Indies, where they are most frequent about the time of the equinoxes, and also in the Indian Ocean, extending from Madagascar nearly to Australia, and from 4° to 35° south latitude, occurring here at the change of the monsoons. In the Chinese region they occur about once in three years, generally from June to November, extending from the Ganges to Japan, and from latitude 5° N. to 25° N. They are here called *typhoons*. The tornadoes of the West Indies and the Indian Ocean are generally accompanied with thunder and lightning, and sometimes showers of hail.

It is worthy of note that in the tropical climates the barometer indicates the approach of a hurricane, the mercury in the tube being depressed or agitated in an extraordinary manner for some time before any signs of a storm appear in the horizon; also during the *first half* of the storm the barometer *falls*, and during the *last half* it *rises*. This is owing to the density of the air increasing from the centre to the circumference of the storm, so that when a hurricane passed diametrically over a district the pressure would decrease, but gradually increase during the last half of the storm. The direction the centre of the storm lies may be always found by standing with the back to the wind, then in the Northern Hemisphere the centre is towards the left hand, and in the Southern Hemisphere to the right hand. This rule is of importance to mariners, showing them how to steer so as to get out of the cyclone. (For "Thunder, and "Magnetic Storms," see 29, 30, 35.)

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* Greek, *ἐτήσιος, annual.*

120. Cyclones and Anticyclones.—According to recent investigations, all variable winds are of a rotatory character. On weather charts it will be noticed certain dotted lines appear every morning. These lines are drawn through places having the same mean barometric pressure, and are termed *isobaric lines*, or lines of equal pressure. The figures attached to them show the height of the barometer in those parts of the countries over which they pass, so that we can see at a glance the general height of the barometer, or, more correctly speaking, the general distribution of atmospheric pressure over the country. The knowledge of the conditions which usually accompany the relations and different distributions of the isobars, and of the movements usually followed by the different systems, is the basis of the study of the weather.

The pressure of the air varies considerably over a large area at the same time; hence it follows that at a certain place, at a certain time, the pressure is lower than in any other region. If observations are taken simultaneously at a number of places, scattered over the country, and marked on a chart, the region of lowest pressure will at once be visible, and also the manner in which the pressure increases on all sides of it. If a line is drawn, connecting all points of lowest pressure, or points not exceeding ·05 of an inch higher than the *lowest*, a small circular space will be enclosed. Lines connecting places where the reading is at the next lowest point, are then drawn. Another space, but not so circular in form, is enclosed. This proceeding is repeated till the highest readings are reached. The outer lines are not nearly so regular as the inner ones, but appear simply as curves.

The space enclosed by the line of least value is called an *area of low pressure*, or a *cyclone*, on account of the winds; and that enclosed by the isobar of greatest value is termed an *area of high pressure*, or *anticyclone*.

At the centre of both cyclones and anticyclones calms prevail, while around their centres the winds blow in a rotatory direction, but in opposite directions. With the former comes generally rain, snow-squalls, and overcast skies, while the latter are generally accompanied by bright, and almost dry weather, and are generally stationary or slow in their movements, cyclones being quicker and more uncertain.

In anticyclones, or areas of high pressure, the barometrical readings decrease in all directions from the centre. Round these areas the wind circulates in the same direction as the motion of the hands of a watch, but, in addition to the motion, has a direction *out from the centre*, which is explained by the hypothesis that the area of high pressure is formed by a descending current of air which must flow outward.

In cyclones, or areas of low pressure, the direction of the wind is exactly the converse of those of the anticyclone; thus, in the Northern Hemisphere, the wind blows *inwardly* in a contrary direction to the movement of the hands of a watch.

Cyclones originate in influences which cause the air over certain large areas to ascend in a vertical direction. This leads to an in-draught of wind rushing in from the surrounding region to supply the place vacated by the ascending air. Were the earth at rest, these currents would all press to one centre with equal force, without being rotatory. It is the influence of the earth's revolution which causes them to assume a vorticose motion.

Our geographical position being right across the track traversed by the numerous cyclones which travel from the North Atlantic over the north-west of Europe, it is easy to see that they have much to do with *our weather*—indeed, much more than the anticyclones, which are usually found established over France and Spain.

Generally speaking, cyclones pass over our islands from west to east, appearing most frequently to be generated over the Atlantic; at least the majority of our storms arrive from this quarter. From continued observations, it is ascertained that the winds always blow towards the place of the lowest barometer readings, or areas of lowest pressure. Hence, by knowing the barometer readings over a large area of country—which are furnished by telegraph—an observer is enabled to trace the march of the storm, and, by means of the telegraph, give warnings to those places where the storm may be expected. This is the method on which weather predictions are based. The Atlantic Ocean, to which we are so near, greatly interferes, for want of more westerly barometric readings, with the power of forecasting, for more than two or three days, and generally a much shorter time, as most of the storms that visit the western coasts of Europe travel from the south-west towards the north-east, with a velocity varying from 20 to 40 miles an hour.

The electric cables, by joining the Old and New worlds together, afford greater facilities for storm-warnings. Many of the great storms which arrive at our shores appear to have their origin in the American Continent. The American meteorologists, from the great area over which observations are collected, are enabled to predict, with considerable certainty, the time when storms may be expected here, and also the particular nature of the storm.

Though the storms do not always happen to exhibit such features as were predicted, or may not even present themselves to us at all, yet, generally speaking, they do occur as forecasted, and do not differ very greatly from what they were some four or five days earlier when leaving the coasts of America.

VAPOUR, EVAPORATION, AND CONDENSATION.

121. Evaporation is the conversion of a fluid into *vapour*. It is produced by the solar heat, which raises water into the atmosphere in an invisible form. Familiar examples of this may be noticed in the drying of wet clothes which are hung out in some open place, and watered streets beginning to dry nearly as soon as watered, &c. At all temperatures water evaporates, even if it is ice. The rate at which evaporation takes place depends upon (1) *the temperature*, the higher the temperature the greater the evaporation; (2) *the amount of vapour in the atmosphere*, as a certain quantity of air can only receive a certain quantity of vapour, after which it is said to be *saturated*, or to have reached the point of saturation; though it must be remembered that the higher the temperature the more vapour will the air be able to contain before reaching this point of saturation; hence the amount of vapour in the air depends solely on its temperature. From this we see that the evaporation is greatest in the torrid zone, it being estimated that on an average 16 feet depth of water is raised annually from the surface of the sea in these parts.

122. Condensation.—*Dew.*—As heat evaporates water and causes it to ascend as vapour, cold, or a decrease in temperature, causes it to condense, forming dew, clouds, rain, hail, snow, &c. Thus, after sunset the earth and air lose the heat they have received from the sun during the day by radiation into space; but the earth, being a good radiator, parts with it more rapidly, thereby causing the moisture in the air to be condensed on the earth's cool surface, forming dew. *The temperature at which dew begins to be deposited is termed the dew-point*, and it varies according to the saturation of the air. It may be noticed that some substances have dew on them while others remain dry. This is owing to the latter being bad radiators and the former good ones. Dew is never deposited in dull cloudy weather. The conditions favourable for its formation are *an unclouded sky* and *a calm night* preceded by *a warm dry day*. On a windy night the radiation would be disturbed, and thereby cause the moisture to be evaporated as soon as formed. Tropical countries favour these conditions, hence the deposition of dew is most copious there, compensating in a great measure for the absence of rain in these parts. In the British Isles dew is heaviest in spring and autumn.

Hoar Frost is simply dew in its frozen state. The chilling effect of radiation reaches but a short distance above the ground, as at two or three inches above the ground it is only about one-half, and at six feet only about one-twentieth. Generally the body itself is about 4° below the temperature of the air just above it.

Fog and Mist.—Fogs result from currents of moist air coming in contact with the colder surface of the earth, the moisture being condensed into the visible form of fog or mist appearing near the surface of the earth. Mountain sides, river valleys, sea coasts, and cold countries favour the formation of fogs, owing to the unequal temperature of the contiguous lands and waters. According to Kaemtz, fogs may be expected frequently where the soil is moist and hot and the air moist and cold. Those occurring in Newfoundland are occasioned by the warm waters of the Gulf Stream being condensed by the cold air of the Arctic current.

123. Hygrometers.—To estimate the amount of moisture in the atmosphere at any given time, instruments called hygrometers are used. The principle upon which most of these instruments are constructed is this: The temperature at which the vapour in the air has its maximum tension is determined—that is, at what temperature moisture just begins to separate from the air, which is called the dew-point. When this point is known it is not difficult to calculate approximately the absolute quantity of moisture in any bulk of air.

Daniel's hygrometer consists of a closed glass tube terminating at both extremities in bulbs, and bent twice at right angles. One bulb is artificially blackened, so that any moisture upon it can be readily seen; this bulb contains some ether, and also a thermometer partly immersed in the ether. The other bulb is empty, and is surrounded with muslin. The whole rests upon a stand, upon which there is another thermometer that indicates the temperature of the air. If some ether is poured on the muslin, the temperature of the bulb falls, and the ether vapour within it, which is derived from the liquid in the other bulb, will become liquid. The space which is thus rendered vacant will instantly be filled with more vapour from the liquid. The evaporation going on in this bulb will lower the temperature of the bulb, and this process can be carried on until it (the bulb) is cold enough to cause dew to be deposited upon it from the air surrounding; the thermometer in the ether will then indicate the dew-point. If some ice is put into a perfectly dry tumbler, the outside of the tumbler will soon become wet from the deposition of dew, just as the bulb containing the ether becomes wet.

Another form of hygrometer is the *wet and dry bulb thermometer.* This instrument consists of two thermometers—an ordinary one, to give the temperature of the air; and another, whose bulb is covered by a piece of muslin or other similar material, to which is attached an absorbent wick, communicating with a vessel containing water. The muslin is thus kept moist by capillary action. The evaporation from the muslin, and consequent cooling of the bulb, being in proportion to the dryness of the air, the difference between the readings of the two thermometers will be greater when the air is driest, and zero when it is completely saturated with moisture.

124. **Clouds** are masses of aqueous vapour in a partially condensed state, differing from fogs in being condensed at a greater elevation, though they are not so high as they appear, as a traveller, for instance, on a mountain may often see clouds floating beneath him. The average height of the clouds is between one and two miles; streaky-curling ones, like hair, are often five or six miles high, the nearest to the earth being those highly electrified. In this country the height is from 2,000 to 6,500 feet, with a thickness of from 2,000 to 3,000 feet. The speed at which clouds move is much greater than appears, owing to their height, as they often move at the rate of from 70 to 100 miles an hour.

Classification.—Clouds are grouped into seven classes—three original, and four compound forms arising from combinations of the others. They are:—

ORIGINAL.—(1) *Cirrus*, or curl cloud. (2) *Cumulus*, or summer cloud. (3) *Stratus*, or fall cloud.

COMPOUND—(4) *Cirro-cumulus.* (5) *Cirro-stratus.* (6) *Cumulo-stratus.* (7) *Nimbus*, or rain cloud.

(1) *Cirrus* clouds appear like fibres, loose hair, or thin streaks. They are the most elevated of all, being not less than three, and often reaching six, and even ten miles in height. They have a tendency to arrange themselves in parallel or divergent bands. At the equator these extend from north to south, but in higher latitudes, as in this country, they stretch from north-east to south-west, varying from that to north-west and south-east. They are supposed to consist of vapour below the freezing point, as minute ice crystals, or pure snow flakes.

(2) *Cumulus* clouds appear in great masses, like volumes of smoke. They are formed after sunrise, gradually increasing and ascending higher as the day advances, disappearing towards evening. If they increase in size at sunset a thunderstorm may be expected in the night.

(3) *Stratus* (*or Fall Cloud*) is a kind of heavy layer of mist or vapour, especially prevailing on a summer evening, rising at sunset or *nightfall* in low damp places, and vanishing at the approach of day. This is the nearest to the earth of all the clouds, and is closely allied to fogs and dew, being formed by the vapours rising from the earth as it cools by night.

The cirro-cumulus, cirro-stratus, and cumulo-stratus, as their names signify, are merely combinations of the original three. The *Nimbus* (or *rain cloud*) is of a greyish appearance, with fringed edges. It is formed from any of the others, except the cirrus, and is always low down, mostly between 1,000 and 4,000 feet from the earth.

125. **Rain** is *vapour* condensed in the air and precipitated to the earth in showers, the condensation being caused by a considerable diminution in temperature. As long as a cloud remains where the temperature is sufficiently high it is capable of containing its moisture, but should it get carried by the wind into a cooler region it is unable to do so. Condensation then sets in, and the several vesicles of vapour uniting cause the weight to become too great to be supported by the air. Hence the drop thus formed falls to the ground.

Rainfall.—By the time the north-east and south-east trades meet, producing the equatorial calms, the air is heavily laden with vapour. Having travelled in each hemisphere over a very large space of the ocean, it now ascends, expanding and becoming cooler, part of the vapour thus condensed coming down as rain. It is thus that we have a region of constant rain at these calms. The nearer we approach the poles the less rain descends. The quantity falling in any country depends on its nearness to the ocean or other large bodies of water, upon the temperature, upon the seasons, and upon the direction of the prevailing winds. The coasts of a country, or those countries where the winds blow chiefly from the sea, receive a greater proportion of rain than the interior. Chains of hills also affect the air much by coming in the way of the winds and causing them to descend. Hence the amount of rainfall depends in a great measure upon whether the country is mountainous or not, and also on the *direction* of the mountains. Thus, for instance, the most remarkable rainfall in the world occurs at Cherrapoonjee, in the Khasyah Mountains, its annual average being 499·3 inches, though in some years its rainfall has exceeded 600 inches. This extraordinary downfall is attributed to the abruptness of the mountains which face the Bay of Bengal. Another good example is furnished even in our own country, where the warm winds of the Atlantic meet the hills and mountains of the west side, especially in the Cumbrian Hills, where—namely, at Scathwaite—the average is 145·1 inches, the west side entirely averaging 45 inches, and the east coast only 27 inches. A similar example is to be found on the west coast of Ireland. The mean annual average for Great Britain is 34 inches, and England, a little over 30 inches. The reason that the east side does not receive so much rain as the west is selfevident—namely, that the mountains on the latter side condense the warm moist winds of the Atlantic, partly preventing their passage over, rain coming down in torrents, and the air which does reach the other side is thus comparatively dry.

In Guiana, Brazil, and North and West India, the average rainfall exceeds 300 inches.

When it is stated, as above, that the mean annual rainfall of a place is 30 inches, it implies that the amount of rain that falls in the course of a year would on an average cover the ground to a depth of that number of inches (30), supposing the ground perfectly level and the water neither to sink into the earth or evaporate. The instrument used for the measurement of rainfalls is called a rain gauge.

126. Rain Gauge.—A common form of rain gauge consists of a copper cylinder of 5 inches in diameter, mounted with a cover having a conical inlet, terminated by a tube which passes into a glass bottle contained inside (similar to an ordinary funnel). This is accompanied by a glass vessel of ½ inch diameter and 12 inches in height, which is graduated so as to indicate one-hundredth of an inch of rainfall. The bottle is taken out after a fall of rain and the contents measured by the graduated vessel. The observations are taken from time to time, and a record kept of the different quantities obtained in the course of the year. The instrument is generally sunk, so that the top may be about 6 inches from the ground and perfectly horizontal. The object is to ascertain the quantity of rain which falls on any particular part of the earth's surface, the quantity being indicated by the depth of the precipitated water which would cover the ground about the spot, supposing the ground to be horizontal and that the water could neither flow off nor penetrate into the soil.

SPECIMEN TABLE OF AVERAGE ANNUAL RAINFALLS OF A FEW PLACES.

Names.	Inches.
Cherrapoonjee	499·3
Vera Cruz (Mexico)	278
Akyab (Arracan Coast)	204
Andes (Patagonia)... more than	200
Scathwaite (English Lake district)	145·1
Glencroe	127·7
Bombay	76·2
Calcutta	66
Keswick (Cumberland)	63
Cahirciveen (Ireland)	59·4
Kendal	58
Madras	56·3

Names.	Inches.
Glasgow	43·3
Manchester	35·5
Cork	35·5
Lisbon	27·5
London	24·2
Paris	19·9

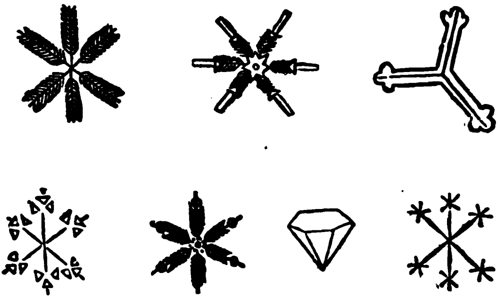
Generally speaking, the greatest rainfall is in the tropics, and gradually decreases as we journey towards the poles. At the tropics its annual average is about 95 inches, but in the frigid zone it is only about 15. As the rain depends much on the wind it seems to follow much the same arrangement—namely, periodical in the tropics, variable in the higher latitudes, and abnormal in certain districts, when it occurs either in excess or is altogether absent. In the tropics the rainy season commences at the changing of the monsoons (p. 127). In general terms, more rain falls from April till October than in the other months, especially in the northern half of the torrid zone, where the wet season occurs at this time, the dry season commencing in October and continuing until April. In the southern half this order is reversed, the dry taking the place of the wet.

127. **Rainless Districts.**—There are some places where little or no rain ever falls, the principal of which are the Sahara Desert, the great deserts of Arabia, Persia, Mongolia, including Gobi, Thibet, &c., and North Mexico and west of Peru, in America, forming as it were one continuous area, varying in breadth from the 15th to the 47th parallel, and in length from 16° W. to 118° E. longitude. The *least* rainfall in the world of which we have record is at Suez, being 1·3 inch. The area of these rainless regions is about 5½ million square miles.

This peculiarity may be attributed principally to the physical features of these districts. Thus, for instance, in the Sahara Desert, deserts of Arabia, &c., the atmosphere is so heated by the hot sands, that it absorbs all the moisture and precipitates none. In other places, as for instance, Thibet, Gobi, &c., distant mountain ranges causes the vapour to condense before it reaches these regions. In other places the prevalence of dry winds may be the cause.

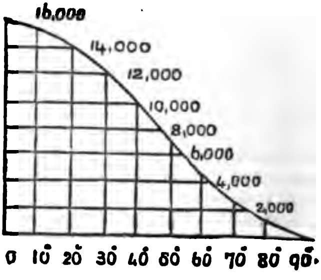
128. **Snow.**—When the temperature of the air is below the freezing point—namely, 32° F.—the condensed vapour must be in the form of particles of ice; hence when they fall to the earth we have *snow* instead of rain, and these frozen particles uniting together form flakes, the size of which depends upon the amount of moisture and the extent of the prevailing low temperature. *Sleet* is formed by the flakes in their descent encountering warm strata of air. Snow

is generally composed of crystals in the form of six pointed or angled stars of 60°. As many as 1,000 different kinds have been noticed.



Snow Flakes magnified.

Snow-line.—At places within the tropics at the sea level, and for 15° or 20° beyond in either hemisphere, snow never falls, the reason of which is obvious. Also in the higher latitudes it only falls during winter and at considerable elevation; but in the polar regions, and at extreme heights in all latitudes, it becomes constant. This limit is termed the *snow-line*, the height of which varies not only with the latitude, which descends constantly as we travel towards the poles, but also with the situation as regards exposure to the sun and rain-bearing winds, the degree of humidity of the climate, and other causes. The accompanying diagram gives a general idea of its gradual descent from 16,000 feet at the equator, down to the level of the sea at the poles. But it must be understood that it does not always follow this rule, as for instance, on the south side of the Himalayas the snow-line is about 4,000 feet higher than that on the north side. owing chiefly to the great dryness of the enormous table-lands of Central Asia, as they increase the radiation of the solar heat, hence the evaporation, and



also to the moisture conveyed to the south side by the warm winds of the Indian Ocean. The highest point to which the snow-line reaches is about 18° south of the equator, namely, in the Andes of Bolivia, where it exceeds 20,000 feet.

HEIGHT OF SNOW-LINE IN DIFFERENT LATITUDES :—

	North Latitude.	Height in feet.
Spitzbergen	78°	0
North Cape	71°	2,400
Sulitelma (Norway)	67°	3,850
Oonalaska	53½°	3,500
Altai	50°	7,030
Alps	46°	8,890
Caucasus	43°	11,060
Rocky Mountains	43°	12,470
Pyrenees	42¾°	9,000
Etna	37¾°	9,750
Himalayas (North)	29°	19,000
Himalayas (South)	28°	15,000
Purace (Andes)	2¼°	15,380
	South Latitude.	Height in feet.
Andes of Quito	0°	15,795
Kilimanjaro	4°	17,000
Andes of Bolivia	16°	17,700
Andes of Bolivia	18°	20,060
Straits of Magellan	53½°	3,540
South Georgia	54½°	0

From the above it will be seen that the greatest change in the snow-line takes place between 30° and 60°.

129. Hail is supposed to be formed in the higher regions of the atmosphere. It consists of snow coated with ice frozen to it in its descent to the earth. It may briefly be defined as *frozen rain.* It occurs in all latitudes and at all seasons. It appears to be connected in some way with the electricity of the atmosphere, thunderstorms often occurring while hail is falling. Hailstones are usually pear-shaped, and small in size, but have been known as large as hen's eggs. *Hailstorms* occur mostly in summer and in the daytime, and most frequently near mountains, seldom occurring in lowland plains within the tropics, but common at several thousand feet of elevation.

Ice is frozen water, or water that has been crystallised by the atmospheric temperature being below or at 32°; for salt water 4½° lower. On close examination it will be found to consist of six-rayed stars, like the characters of snow, and to be of pure water. (For "Expansion," &c., &c., see 47.) Ice has, under some circumstances, been formed at the bottom of rivers and ponds—called *ground ice.* Occurrences of this description have been noticed in the Thames, in the rivers of Siberia, and also in the Baltic.

For **Ground Ice** to be formed the water must be in motion, so that the mechanical action entirely mixes the body of water, causing it to be all the same temperature. Then, when the whole is reduced to the freezing point, ice begins to form at the bottom, owing to the motion being less there and to the water being in contact with substances having a cool surface. When the sky is cloudless, and when, therefore, radiation from the bed of the river goes on most rapidly, ground ice forms most readily.

According to Dr. Carpenter, ice in sea water often begins to form at the bottom. He thinks that sea water differs from fresh water, and continues to contract down to its freezing point; so that the more it is cooled the heavier it becomes, because its bulk diminishes. It therefore sinks in proportion to its degree of coldness, and in this manner it is that the coldest water always comes to be at the bottom in the sea. This ice forming at the bottom has been observed by Arctic voyagers and Baltic fishermen; thus when the season is first changing, the fishermen in the Baltic or in Norwegian fiords observe the ice in the first instance to come up in little discs or plates from the bottom, something like so many jelly fish.

Avalanches are accumulations of snow, or snow and ice, which frequently roll with great violence from lofty mountains—as the Alps for instance—into the valleys or plains below, carrying destruction and ruin. There are three descriptions. (1) The *wind* or *dust avalanches*—that is, fresh-fallen snow carried down into the valleys in the form of dust. They are very light, hence not so destructive. (2) *Mountain, snow, hail, or thunder avalanches.* These fall by their own weight, carrying with them the ground on which they lie, together with trees, rocks, &c., and mostly occur in spring. (3) *Earth avalanches*, or *landslips*, when they occur, are by far the most destructive. The earth, having been weakened by much continuous rain, *slides* down into the valleys with everything upon it—houses, trees, and even entire forests.

130. **Glaciers** are enormous masses of ice, formed on mountains above the snow-line, which creep down into warmer regions, where they melt and disappear, giving rise to streams, as, for instance, the Rhine and Rhone from the glaciers of the Alps. In mountain gorges they descend as ice-streams, the ice being partly plastic, though in appearance rigid. It differs also from ordinary solid ice, being of a blue-veined structure, due to great pressure. These streams of ice

travel at the rate of from 10 inches a day in winter to about 20 in summer, and follow the same laws as rivers of water—the velocity being greatest in the centre.

The *rate of movement* of glaciers has been determined in the following manner:—An observer, in 1827, had built a hut on one of the Swiss glaciers for the purpose of making observations, and the exact position of this hut determined when it was erected. In 1841 it was found 4,884 feet lower down the valley, giving an average motion of 349 feet every year. Another result, obtained from the distance a ladder, which had been accidentally left on one of the arms of the Mer-de-Glace, had been carried by the motion of the glacier during a period of 44 years, is 375 feet per year.

By the use of surveying instruments and stakes driven in the ice, the daily motion of a glacier may be determined. In this way it has been found that the middle of the Mer-de-Glace moves through 20 inches a day in summer and 10 in winter.

The middle travels faster than the sides. This may easily be shown by a row of stones being laid straight across one day. They will the next be in a different position. The central stones will have crept forward perhaps 20 inches, while the marginal ones but 5 to 15, and the others in proportion.

The glacier, in its journey over rocks, &c., often causes great cracks or clefts of great depth, called *crevasses*, and tears away the loose rock and *débris*, which it carries with it, depositing these *moraines*,* as they are termed, when the glacier melts away at the snow-line, beginning to flow then as streams of water.

Glaciers are most abundant in the Alps, Himalayas, Norway, New Zealand, and continually in Arctic and Antarctic regions.

The most extensive occur in Greenland, some of which are 45 miles broad and from 350 to 500 feet in height. Large ones also occur in the Himalayas, the Rocky Mountains, Iceland, Spitzbergen, &c.; but the most remarkable are those of the Alps, where over a thousand distinct glaciers occur. Some of the chief are Mer-de-Glace, with an area of 18 square miles, and Glacier-de-la-Brenva, both in the Mont Blanc group; the Zermatt Glacier, in the Monte Rosa group; and the Great Aletsh Glacier, with an area of 34 square miles, in the Oberland group.

131. Denudation.—On a previous page we noticed the effects of the sea on the earth's crust. There are, however, other forces at work, whose combined energy produce far greater results in the process of levelling and filling up, going on incessantly all over the world. Changes of temperature—water in its several states of mist, rain, ice, assisted by the carbonic acid it takes up from the soil and atmosphere—and many other agencies, the effect of which may be seen nearly everywhere. It is to these means hills and valleys owe their shapes. Thus the soft and modern rocks are attacked by these agencies and carried away, leaving the harder ones standing. Tablelands of small elevation and moderate extent are converted into hilly districts by the gradual widening and intersection of the valleys by aërial denudation. We will here briefly mention the chief of the agents, showing the manner in which they act.

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* These *moraines* are called *lateral* when they line the sides of the glacier; *terminal* when they are deposited in heaps at its extremity; and *medial* when two glaciers join, causing the inside moraine of each to unite.

132. **Heat of the Sun.**—When the sun shines fiercely on a summer's day it crumbles wet earth and clay and leaves a dust. It also heats the hard rocks, such as granite, gneiss, &c., so that they do not get cold again until nightfall. The minerals composing these rocks expand when they are warmed. There being different kinds of minerals in many of the rocks, some will expand more than others, thus causing, as it were, a *pulling* and *dragging* underneath the surface, and often a piece cracks or flakes off.

In like manner, in the process of cooling, some will contract more quickly than others, so that again there is a chance of breakage.

The **Air,** or **Atmosphere** works both mechanically and chemically. Winds, cyclones, and gales not only remove dust and the crumbled stuff off the land, but even blow down rocks. They increase the force of the rain by giving it a greater driving or pelting power, and in the hotter parts of the globe the furious winds and rains are as destructive as torrents of water. But wind of the gentlest kind does a great deal of mischief to some mountains and hills, enlarging their valleys in a remarkable manner and altering their shape. Thus, for instance, in Eastern Arabia, where rain seldom or never falls, the gentlest gales *sand-scrub* the rocks and do the work of water, and even on our own sea-coast, far out of the reach of water, the sides of many a rock are furrowed and worn by this method.

There is another manner in which the atmosphere acts on the sides of rocks and hills. This is of a chemical nature. The air, as previously stated, consists principally of oxygen and nitrogen gases *mechanically* combined, with a small quantity of carbonic acid gas, oxygen, and carbon chemically combined. Two of these components of the atmosphere attack many stones, surfaces, and soils, and, by changing their chemical condition, cause insoluble matter to become dissolvable. The oxygen acts on such minerals as contain iron, and the carbonic acid, assisted by water, dissolves away the limestone rocks, or removes the lime part of the surface of a stone which contains it and sand.

133. The Action of Rain, Springs, Rivers, Snow, and Glaciers on the Earth's Crust.—As previously mentioned, water is the principal mechanical agent at work in the process of destruction and construction. By infiltration it sweeps away the particles disintegrated by chemical agents.

Rain.—Part of the rain which falls on the surface runs off in brooks and rivers. Another part percolates through the ground until it meets a less pervious rock, where it forms a reservoir, or escapes through the sides of a hill, &c., forming springs. (See 92.) It is to the effect of rain that *landslips* may be attributed. The water, soaking through the ground, accumulates on a bed of clay, or some such stratum, and loosens the cohesion between it and the upper beds, when if the strata are favourably placed, it may happen that the upper layers will slide over the slippery clay in which the strata are inclined. The rainwater which flows over the surface continually sweeps with it the minute particles of sand, rock, &c., which the action of the weather has loosened.

We must also remember that rain in descending is not perfectly pure, but contains slight traces of carbonic acid. On reaching the earth more carbonic acid is dissolved. The water has now a greater power to act on the hill-sides as it runs down in streams, the gas combining with insoluble matter to make them soluble and ready to be washed away.

Rivers.—Streams in their course through hilly regions wear channels for themselves, and carry along with them the displaced materials. (See "Deltas.") They have generally a tendency to wind about, in many cases a great number of convolutions occurring in the space of a mile or so. The reason of these tortuous courses may be attributed to the operation of the natural law, *that a mass of matter in motion has a tendency to move in a straight line.* (Also see 93.)

Frost.—When water gets into the joints and crevasses of a rock, and then becomes frozen, it expands, forcing apart the blocks and particles, so that as soon as the thaw comes the loosened particles and pieces fall asunder. *Snow* also is at times a disintegrator of rocks—namely, when accumulated on mountains and sliding down as avalanches. *Glaciers*, in their motion over rocks, exert great erosive power, and (not like water, dividing on meeting an obstacle) push everything before them that gets in their way. By this means all loose stones in the bed of the glacier are torn up, making it a smooth undulating surface, with scratches or furrows running parallel with the stream of ice, caused by angular fragments of rock, which have fallen through crevices from the surface of the glacier, being dragged along with the weight of the ice above them.

It is in this way *Roches Moutonnees* (Fr., roche, a rock, and moutonné, sheep-like) are formed. Thus the glaciers by their action on the rocks cause them to become ground and polished, though the ice does not plane the surface evenly, but merely removes the jagged and projecting points, thereby leaving in places rocks possessing a peculiar rounded appearance, some of which from their shape have been likened to the backs of sheep.

To the excavating action of glaciers Professor Ramsay attributes the rocky basins in which most mountain lakes lie. He points out that in the region of the Alps all the lakes lie in the dried channels of the ancient glaciers. And again in places where we know glaciers have been in past ages, lakes occur more frequently than in warmer regions, as for instance in Northern Europe and North America. Even in the United Kingdom where traces of the glacial action are found—such as in Westmorland, Cumberland, Wales, Killarney, and various parts of Scotland—there occur the lakes.

It is no doubt to this very agency that many mountain valleys owe their origin.

134. Phenomena of the Arctic and Antarctic Regions. The *Arctic Regions* are the high latitudes surrounding the North Pole, and the *Antarctic* the regions surrounding the South Pole. As they are the farthest from the equator they are the coldest regions of the world, being inaccessible to man beyond the 84th parallel of latitude. The highest point but one ever reached is 83° 20′ 30″, by the arctic explorers of 1876, under Captain Nares, namely Commander (now Captain) Markham and Lieutenant (now Commander) Parr, with 15 men under them. The Alert, one of the vessels under Captain Nares, also reached a higher latitude than had ever previously been reached by a vessel, namely, lat. 82° 24′. In May, 1883, the American explorer, Lieutenant Lockwood, following the coast of Greenland, pushed forward as far as lat. 83° 24′ N., and thus got four miles nearer the pole than Captain Markham. The temperature during the winter months is so low that mercury is of no use in the thermometers to measure the *cold*, as it becomes frozen, remaining so for more than a month at a time. Spirit thermometers were used, showing a temperature of −74°, or 106° below the freezing point, in March, though the thermometer may register, during the summer months, a temperature nearly equal to the mean of the tropics. The seas of the polar regions are closed during the greater part of the year, being only open for a few months in summer. The extent to which the Arctic Ocean is frozen is not known. At a degree of latitude varying with the season of the year, ships are barred from going northward by a barrier of frozen ice. The outer edge of this barrier gets split and broken off into vast mountains of ice during the summer, commencing at the latter end of April, drifting towards the south. The largest of these ice mountains are formed from the glaciers of these regions, which spread almost over the entire surface, gliding on as rivers of ice till they reach the sea-shore, and there, losing their support, the front parts break off, and float away as *icebergs* (ice mountains). Some of these bergs are several miles in circumference, and from 50 to 250 feet above the surface: hence the entire thickness of the greatest are 250 × 9 = 2,250 feet, the specific gravity of ice being ·9 and water 1. In the Atlantic, icebergs from the Arctic regions have been carried by the polar current as far as the 44th parallel of latitude, and from the Antarctic they have reached the Cape of Good Hope. The ice that forms on the surface of the sea is called *field ice.* It forms in the winter and breaks up in the summer. A small field is termed an *ice floe*,, and one much broken up forms a *pack*, or *pack ice.*

Red Snow in the Arctic Regions.—Red snow is a phenomenon which is often observed in the polar regions. Captain Ross discovered on the shore of Baffin's Bay a range of cliffs extending for more than eight miles covered with a brilliant *red snow*, in some place 12 feet deep. The cause of this appearance has been found to be due to the presence among the snow of a *very minute plant*, which Sir William Hooker named *Palmella nivalis.* This snow has also occasionally been met with in the Alps and in Scotland.

Day and Night in these Regions.—As we approach the poles the inequality between the days and nights becomes greater and greater, until at the poles themselves a *day of six months* alternates with a night of the same duration. The most distinct parallels that the sun describes north and south of the equator are 66½° from the latter, and 23½° from the poles Hence when the sun is in the tropics all the polar circle in that hemisphere will be within the illumination of the sun, as it will be with 90° of that luminary. During the same time the other polar circle will be in darkness. Therefore during the year they have one day of exactly 24 hours and one night of similar length.

The change from short days to long ones, and *vice versa*, in these regions takes but a very short time. We may fancy that during the six months that the sun is absent there would be total darkness, but such is not the case, owing chiefly to the reflection of the sun, namely, *twilight*, which in these regions lasts for months—at the north pole from September 22nd to November 12th, and from January 25th to March 20th. Besides the twilight there are the stars, and also the snow on the ground, which mitigate the darkness, the moon also appearing every 14 days. Very few animals or birds inhabit these parts. A few musk oxen, hares, and ptarmigans reach as far as latitude 82°.

One or two geological facts regarding the Arctic regions have been brought to light by the late expedition, bearing on the changes in the climate in those regions. Miocene beds, including a thick seam of coal, were found to exist as far north as latitude 81° 44′. The shales and limestone of the same formation contain abundant examples of the *flora* (flowers) of that epoch, thereby proving that at a comparatively recent geological period there existed a temperate climate within 500 miles of the north pole ; and according to Mr. C. Markham excellent coal was found in latitude 82°, and impressions of leaves, &c., were brought back, showing that luxuriant forests had grown within 450 miles of the pole. Wood has also been discovered in the now frozen regions, *with the bark on,* having evidently grown where found, thereby showing that there must have been *great and rapid changes of climate in a comparatively short period* in the polar region.

The Antarctic Ocean has not been explored so high in latitude as the Arctic, the highest latitude reached being 78° 15′, in 1841, by Sir James Ross. It is supposed that nearly the entire area, embraced by the Antarctic circle, is occupied by land, covered continually with snow. Two volcanoes, if not more, exist in these regions—Mount Erebus, 12,400 feet above the sea level, and Mount Terror, about 9,000 feet; the former is in a state of constant activity, and the latter extinct.

The cold is more severe than in the Arctic region. For instance, at lat. 64° S., Captain Nares found the temperature of the atmosphere to be 55′ below freezing point (31·5°) in February, which is lower than the temperature of the Arctic region 10° nearer the pole.

CLIMATE, AND CAUSES AFFECTING IT.

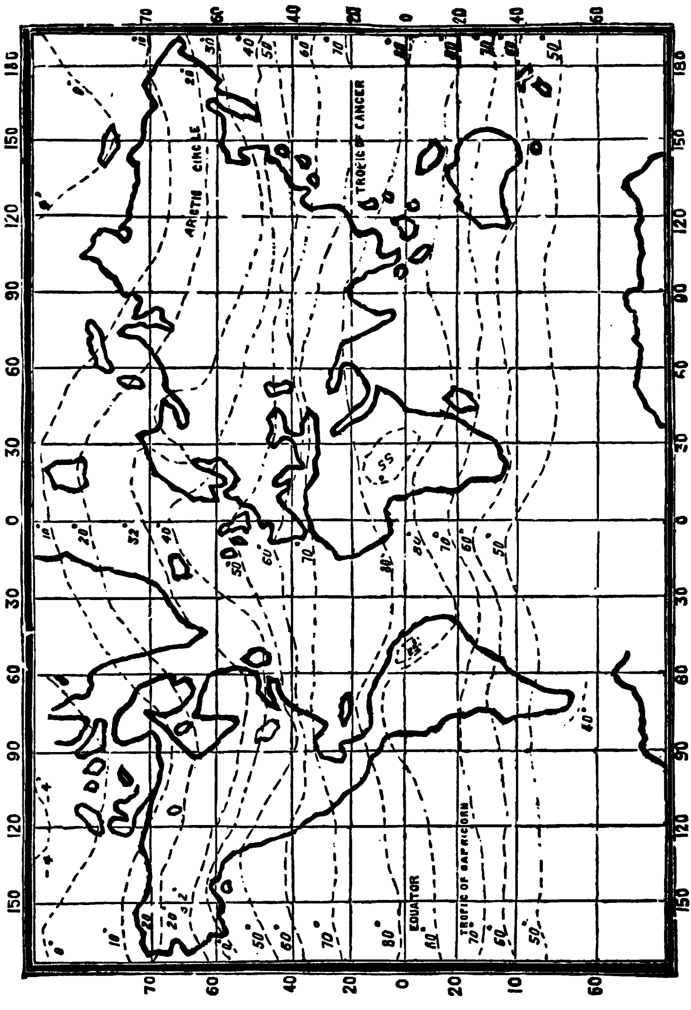
134. Under the term "Climate" we speak of the *general weather conditions* of any district, as mild, or severe.

Climate depends on numerous circumstances, the chief of which are—(1) Latitude. (2) Altitude. (3) Nearness to the sea. (4) Distribution of land and water. (5) Mountains. (6) The prevailing winds and ocean currents, &c. The principal cause affecting climate is the latitude, so that we may say *generally* that the climate of a place is warmest the nearer it is to the equator, or that its temperature diminishes in proportion as its latitude is greater, or more correctly in proportion to the square of the cosine of its latitude. This is obviously owing to the greater obliquity of the sun's rays with increasing latitude. The second principal cause is the *altitude.* (See "Snow-line," and "Height and Pressure of the Atmosphere," 128, 101.) Thirdly, its nearness to the sea, depending upon the unequal reception and radiation of heat by land and water. The heat falling on the land is partly absorbed and conducted downwards into the soil, and partly radiated into the atmosphere. The greater part of that conducted in the earth (which never sinks more than 70 feet, and for practical purposes may be regarded as within a few feet of the surface) is given off by night, but the remainder accumulates day after day all through the summer, keeping it in store to return to the atmosphere in winter. On the other hand, the rays of heat falling on the water are much more readily absorbed, and also radiate more slowly. Hence, there will be a much greater store of heat accumulated in the waters of the ocean during summer than in the earth, so that it will have a great deal more heat to return in the winter than the earth. It is owing to this that islands and seaboards have a more equable climate than those in the inside of a continent. For instance, contrast the climate in winter of any place in England with that of any place in the same latitude in Russia; or, again, the comparatively cool summers and mild winters with the interior of Germany, which experiences excessively hot summers and cold winters. Such places as the British Isles, New Zealand, &c., are said to possess an *insular* climate, and the interior of Germany, Russia, &c., *continental*.

The position and direction of great mountain chains have also a great influence on climate. Thus, they may either protect the country from hot or cold winds, or, by chilling moist air currents, they may cause them to precipitate most of the vapour as rain, and to pass over as dry winds (see 125).

The prevailing winds and ocean currents also exercise great influence on the climate, as they may be either cold or warm, &c., especially in the case of the Gulf Stream, and the Arctic and Antarctic currents. The former, carrying warmth and moisture, lessens the winter climate of the west side of Europe, while the Arctic current brings cold, tempering the summer climate of the eastern part of North America. The direction of mountain chains and the cultivation of a country also influence the climate.

Representation of Climate.—From the above considerations it will be seen that the parallels of latitude do not represent the belts of corresponding climates. So that places having the same summer temperature may readily be known, long series of observations have been taken, and lines of equal heat, called *Isotheral Lines*, have been drawn, showing these places at a glance. In a similar manner, lines are drawn through places having the same winter temperature; these are called *Isocheimal Lines.* Lines drawn through places having the same mean annual temperature are called *Isothermal Lines.* (See map.) From the map it will be seen that the line of


ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
180
150
120
90
60
30
0
30
60
90
120
150
70
60
40
20
0
20
40
60
10°
20°
30°
32°
40°
50°
55
60°
70°
80°
40°

greatest heat does not coincide with the equator but lies north of it, from about 150° west longtitude, across both hemispheres, falling below it in the island of Borneo. The average temperature of the line is about 84° F., being hottest near the Red Sea. The hottest portion of the open sea is in the Pacific, a few degrees south of the equator, where the average temperature of the air is the same as the hottest portion of the land. In like manner, the North Pole is probably not the coldest part of the Northern Hemisphere. Thus between lat. 75° and 80° at the North of Siberia in long. 120°E, and also in long. 80° W. north west of Baffin's Bay, the mean temperature is only about 1°. Other lines termed *Geo-isothermal*, or lines of equal surface temperature, are drawn, passing over those portions of land and sea in which the mean annual surface temperature of soil and sea respectively is uniform. These lines are employed as being more definite than *isothermal*, which applies equally to air, land, and water. Lines drawn through places having the same mean barometric pressure are termed *isobaric lines.*

Climates are generally grouped into three classes. (1) Those in which the temperature of summer is but little in excess of that of winter, are called *insular* climates, as in this country. The mean difference between summer and winter here is only about 20°. (2) Those in which the difference between summer and winter is strongly marked, owing to their distance from the sea. These are termed *continental.* Central Russia and Germany, in the same latitude as England, have a range of 86°. (3) Those in which the difference is very great. For instance, in Siberia the difference amounts to 106°, the summer temperature being 62·2°, and the winter – 43·8°. These are termed *extreme* climates. Also, regarding the distribution of the climate, there is one fact not to be lost sight of, and that is—the Northern Hemisphere is about 3½° warmer than the Southern one, owing to the much greater extent of sea to the south.

Meteorology is the science which treats of the atmosphere and the various causes which affect its condition. The most important of these are temperature and watery vapour, which, by their combined effect, produce variations in pressure, wind, and rain or other downfall. Societies for taking observations respecting these factors of weather have been in existence several years, and observers scattered over the length and breadth of the land. The instruments chiefly employed are, the *Thermometers* (wet and dry), to furnish data for computing the humidity of the air; *Barometers*, for measuring the pressure of the atmosphere; *Rain-guages*, for calculating the depth of rain-fall; and *Anemometers*, for observing the velocity of the wind at a particular time, the total horizontal movement of the air during a lengthened period.

135. Respecting Telegraphic Weather Information. Instantaneous reports, or nearly so, are daily received at the London Meteorological Office, from various stations in the United Kingdom, as well as a few on the Continent. These observation are compared and the results forwarded to the outports, and permission given to hoist the storm drum. To form an idea of the method pursued, we must bear in mind there are two constant principal wind currents, N.E. and S.W. (See Report of Mr. Babington, of the Meteorological Department, Board of Trade), of which the characteristics, especially with regard to temperature and degree of moisture, are totally distinct. All varieties of wind and weather in these latitudes may be traced to the operation of these two main currents, singly, in combination, or in antagonism; at times running in parallel lines, but in opposite directions, frequently superposed and occasionally meeting at various angles of incidence. Upon the relative prevalence or failure of one or both of these currents, all conditions of weather appear to depend. It is, therefore, clear that changes must begin at some places earlier than at others, hence advantage is taken of the telegraph to transmit to this department observations taken at the outports. These afford the means of forming a good opinion respecting the nature and probable course of such changes. (See 120.)

Respecting these forecasts, there are a few grand rules, which though not always free from disturbing causes, may be considered as generally holding good :—

(1) The essentially distinct characteristics of the two main currents should never be forgotten.

(2) The direction of wind is usually from the place of high barometer towards the place of low barometer.

(3) The force of the wind is usually proportional to the *difference* of barometric pressure, not to the actual pressure.

(4) It was believed by the late Admiral Fitzroy that there exists a lateral transference of the whole body of atmosphere eastward.

(5) Atmospheric disturbances are often preceded by disturbances on electric wires above ground, and also on submarine wires.

The probability of lightning occurring seems to be in proportion to the amount of vapour and the suddenness of its condensation. Heavy rain, even when unaccompanied by lightning or thunder, is always accompanied by the manifestation of atmospheric electricity of unusual strength. No doubt the frequent association of heavy rain with thunderstorms is due to the fact that air, when laden with globules of water, acquires the power of conducting electricity which it does not possess in their absence.

ANIMALS AND PLANTS.

136. Their effect on the Atmosphere.—*Animals* inhale atmospheric air, and retain some of the oxygen, which combines with the elements of the body. The chief of these elements are carbon, hydrogen, phosphorus, nitrogen, sulphur, calcium and oxygen. The carbon, which is disengaged from the venous blood, is by the action of respiration (slow combustion), united with the oxygen in its passage through the lungs, forming carbonic dioxide which is exhaled by the mouth and nostrils. The nitrogen is exhaled unaltered. Hence briefly, the action of animal life on the atmosphere is to decrease its free oxygen, and to increase the amount of carbonic dioxide (CO_2). When animals die and decay, the elements of which they are composed are decomposed and new compounds formed. Thus, ammonia, sulphuretted and phosphuretted hydrogen gases, water, carbonic dioxide are given off, and phosphate of lime remains.

Plants.—The organic portion of plants consists chiefly of carbon. oxygen, hydrogen and nitrogen, in very different proportions. These elements they derive from their food, which enters partly by the roots and partly by the pores of the leaves and of the young twigs: in other words, the roots feed on the soil, the leaves on the *air*. The leaves, the green stems of young shoots, and green stalks of grasses, &c., inhale their food in a gaseous state. During the day they absorb $C\,O_2$, and in the presence of sunlight decompose it into its elements, C & O, retain the C, and give off the O. At night the process is partly reversed, O being absorbed and C exhaled; but as the process is not nearly as rapid as the former, the plants gain a large portion of C from the atmosphere.

Hence the action of vegetable life on the atmosphere is to balance that of animal life, thereby causing the composition of the air to remain constant or nearly so. Thus the healthy state of a country is heightened by cultivation.

Carbon is also partly supplied by the roots as well as the leaves. Thus vegetable matter in decaying gives off carbonic dioxide ($C\,O_2$) water, (H_2O) ammonia, ($N\,H_3$) and nitric acid, (N_2O_5). From the $C\,O_2$ the roots obtain the carbon food.

Respecting the further balancing of the atmosphere, or the maintaining of it in its normal state, the experiment of Dr. Saussure furnishes us with important information; he has shown that the upper strata of the air contains more $C\,O_2$ than the lower, which are in contact with plants, and that the quantity is greater by night than by day, as might be expected. In our winter, when vegetation is torpid, and CO_2 formed in excess by combustion in producing artificial light and heat, our supply of O is derived from the tropics and warm climates, where vegetation is perennial, in exchange for which our excess of CO_2 is conveyed by the wind to furnish food for the vegetation in the tropics. In this manner the the carbonised air of the temperate zones is exchanged for the purer air of the tropics. Besides carbon, plants feed on hydrogen and nitrogen. Though all the organs of plants contain carbon and hydrogen, the principal mass of every vegetable is composed of carbon and water, or, rather, the O and H are in the proportions to form water, viz., by weight, 1 part H to 8 parts O. Thus, woody fibre, starch, sugar and gum are compounds of carbon with the elements of H_2O. Most of the organic acids met with in plants consist of C and O and H, while the third class of vegetable compounds, such as wax, the resins, volatile and fixed oil, consists of C and H with no O, or with less than would form H_2O with the H. Hence the hydrogen of plants is derived from the decomposition of H_2O in the sap. When the H is appropriated by the plants, they give up to the atmosphere a quantity of O, in the proportion of the constituents of H_2O by weight, viz., as one is to eight. We thus see that the decomposition of H_2O by plants, is another most important means in the hands of nature for purifying the atmosphere.

The nitrogen is derived by the roots in the state of ammonia (NH_3), which results from the decay of animal matter. NH_3 is also discharged with the atmosphere in the gaseous state, in which form it readily unites with CO_2 to form carbonate of ammonia. Ammonia and its compounds being extensively soluble in water, every shower of rain condenses some and conveys it to the soil. Hence rain water must always contain traces of ammonia.

Another source of nitrogen in plants is nitric acid (N_2O_5.) This is generated in compost heaps, and generally where vegetable matter decays in contact with the air. It is also formed in the atmosphere during thunderstorms by the action of electricity. The acid thus formed is washed down into the soil, where it unites with potash, soda and lime ; these nitrates being soluble, are taken up by the roots of plants. During the germination of seed, O is taken from the air, and CO_2 produced.

137. **Under the term "Life"** is embraced all that appertains to the vegetable and animal kingdoms, subjects to which really belong to Biology* (Botany and Zoology). The part to be now noticed is

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* *Bios*, life. *Logos*, a discourse.

their dependence on climate, and other conditions regarding their distribution.

In speaking of animals and plants we group together those forms which possess much in common as *genera*. These we split up into species, and, for the sake of brevity, the term *flora* is used to designate the plant life of a region or epoch, and *fauna* to designate its animal life. The area within which a given plant prevails is called its *habitat* or *area of distribution*. *Plants* are divided into two classes, namely, *cryptogams*, or non-flowering plants, embracing ferns, mosses, lichens, seaweed, fungi, &c.; and *phenogams*, or flowering plants, as the pine, chestnut, maple, spruce, &c. The number of species known is about 130,000, six-sevenths being flowering plants, and the remaining one-seventh non-flowering. It is calculated that there are upwards of 220,000 species existing on the earth.

138. Distribution of Plants according to Climate. The surface of the globe has been divided into eight zones bounded by *isothermal lines*, or mean temperature. (1) The *equatorial zone*, or region of *palms* and *bananas*, bounded by the isotherms of 79·3° F. on each side of the equator. This zone contains the greatest variety of species and the most luxuriant, the principal of which are the palms, banyans, bread-fruit trees, bamboos, orchids, arborescent grasses, &c. (2) The *tropical zone of tree-ferns and figs*, between the isotherms of 79·3° F. and 72·5° F. each side of the equator. Besides the ferns and figs, &c., many equatorial plants are found, as well as coffee, cotton, pineapples, sugarcanes, cinnamon, logwood, indigo. (3) The *sub-tropical zone of laurels and myrtles*, between 72·5° F. and 68° F. (4) The *warm temperate zone, or region of evergreens*, between 68° F. and 54·5° F., also includes oaks, figs, chestnuts, olives, oranges, the vine, pomegranates, and many other sub-tropical forms; of grain the chief is wheat. (5) The *cool temperate zone of deciduous** *trees*, between 54·5° F. and 41° F. This zone includes all English trees and plants, and beyond it the cultivation of wheat does not extend in the Northern Hemisphere. (6) The *sub-arctic zone of coniferous trees (pine, larch, spruce, juniper, &c.)*, between 41° F. and 36·5° F. In the Northern Hemisphere it is the zone of firs and willows, and in the Southern it embraces a few barren islands. (7) The *arctic zone of the birch and pine in the Old World and the rhododendrons in the New* between 36·5° F. and 41° F. This zone is marked by the dwarf birch, alder, and willow, few pines and firs, and by grasses, and numerous lichens and grasses in the north. (8) The *polar zone of lichens and mosses* (cryptogams), between the mean summer temperature of 41° and 36·5° F. In this zone there are no trees nor bushes, nor any cultivation of plants for food. Zone 1 embraces the central regions of Africa, Ceylon, the South part of the Indian Peninsula, Malaya, the Indian Archipelago, the northern parts of Australia, New Guinea, and other Pacific islands in the same latitude; a large portion of equatorial South America, including Columbia, Peru, Guiana, and the northern parts of Brazil. Zone 2 embraces, in the New World, Bolivia, Brazil, and Paraguay in the Southern Hemisphere; the West Indies, Yucatan, Guatemala, and part of Mexico, in the Northern; and Nubia, Senegambia, Madagascar, Mauritius, and North Australia, in the Southern Hemisphere, and South Arabia; India, Burmah, and Southern China in the Northern Hemisphere. Zone 3 embraces South Africa and Australia, Paraguay, La Plata, and Chili, in the Southern Hemisphere; and North Africa, Egypt, Syria, North Arabia, Persia, Northern India, part of China, the Southern States of North America, Mexico, and California, in the Northern Hemisphere. Zone 4 comprises the south of North America, in the New World; the southern part of Europe, Asia Minor, the north of China, and Japan, in the Old World. Zone 5 embraces our own country, the north of France, and Germany, in the Northern Hemisphere; Tierra del Fuego, Falkland Islands, and Kerguelen's Land, in the Southern Hemisphere. Zone 6 embraces the northern parts of Siberia, Norway, the Faroe Islands, and Iceland. Zone 7 includes the Arctic regions, as far as inhabited; potatoes, turnips, carrots, cabbage, &c., even growing as far as 71° N. There is no equivalent zone in the Southern Hemisphere. Zone (8) embraces the polar regions where it has been remarked that there are more genera and fewer species.

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* Trees which cast their leaves in winter.

139. In a similar manner, in ascending from the level of the sea, we have at different heights distinct changes of vegetation. This ascent (hypsometrical) is also marked by similar belts. Thus, near the equator, in ascending a lofty mountain, we may pass the same zones of flora as in travelling to the poles. For instance, at the bottom of the Alps there are vineyards in the warm climate; as we ascend higher up we pass through a succession of oaks, sweet chestnuts, and beeches, until we reach the elevation of the stunted pines, &c. Thus at the height of 2,000 feet the vine disappears; at 3,000 feet the sweet chestnuts cease to thrive; at 4,000 feet the oak follows the same example; at 4,700 feet the birch retires; and the fir at a height of 5,960 feet, after which no tree appears. The rhododendron reaches to the height of 7,800 feet, and the herbaceous willow to about 8,150 feet; after which we come to the lichens and mosses, which still struggle up to the snow regions. Again, around the base of a mountain in the torrid zone the region of *palms* extends to between 3,000 and 4,000 feet. Above this region extends another zone of about 1,000 feet, which is the zone of *figs and tree-ferns*, the next 2,000 feet including the region of the vine, above which appear the *ordinary trees*, to the height of 10,000 feet; and from this height to 11,500 feet we have the region of *pines;* for the next 2,000 feet the region of the rhododendrons; and for the 1,500 to 2,000 feet following appear the mosses and lichens. It would far exceed the limits of this elementary work to give all these *hypsometrical* zones, as they are termed, but the above will serve as examples.

Not only has the climate great influence on the flora of a country, but also the soil, some prospering in one kind and some in another: and lastly, the amount of moisture affects the distribution directly and perceptibly. For instance, in South America nothing seems to thrive until the rainy season sets in.

Marine Vegetation.—As on land, so in water plants have their fixed and natural distribution, both horizontally and vertically, though not so marked, owing to the greater uniformity of temperature.

140. Of the Four Quarters of the Globe America excels every other in the variety of its flora, and in luxuriance and splendour. It is to this country that we are indebted for the potato, maize, cocoa, tobacco, &c.; while they in their turn are indebted to other countries for corn, sugar cane, coffee plant, cotton plant, &c. Australia possesses scarcely an edible plant indigenous to it. The fruits now there have nearly all been introduced from Europe, including the vine, fig, orange, peach, &c., which flourish in the greatest luxuriance. Its own native trees are all evergreens, and chiefly gum trees, having more than a hundred species. It also possesses many plants which occur only there.

Limits of Important Plants.—In the Northern Hemisphere the limit of trees is roughly taken to be the isotheral line of 50° (see map), but in the Southern they grow all over the land, with the exception of the Antarctic regions. The northern limit of the cultivation of grain is nearly that of the isotheral of 55°. Barley ranges from the isotheral of 55° to 70°; rye from 58° to 70°; oats from 58° to 72°; wheat 59° to 75° (cannot grow in north of Scotland); maize 65° to 80°; rice 80°. The *vine* ranges in the Northern Hemisphere to about 51° N. latitude in the Old World, and only about 40° in the New, its limit in the Southern Hemisphere being the same in each, namely, about 40° S. latitude.

LIST OF A FEW OF THE CHIEF VEGETABLE PRODUCTS AND THE CHIEF COUNTRIES OF THEIR PRODUCTION.*

ALMOND, France, Spain, Italy, Levant, *Barbary*.

ALOES, Bombay, Arabia, Cape Colony, West Indies, north of *Cape of Good Hope*, and *Socotra*.

ARROWROOT, East and West Indies, Bermudas, South America, Africa, *India*.

BANANA, all tropical and sub-tropical countries, *Malayan Archipelago*.

BREADFRUIT, *South Sea Islands*, and *East Indies*.

CACAO (Cocoa), all tropical and sub-tropical countries, *West India Isles*, *Caraccas*, &c.

CAMPHOR, *China*, *Japan*, Java, *Cochin-China*, *Borneo*, and *Sumatra*.

CHICORY, England, Germany, and Belgium.

CINNAMON, *Ceylon* and West Indies.

COFFEE, Arabia, South and Central America, *Abyssinia*.

COTTON, United States, *West Indies*, Brazil, Egypt, the East Indies.

CURRANTS, Greece, including the Ionian Isles.

FIGS, all tropical and sub-tropical countries, especially around the Mediterranean.

FLAX, Russia, Prussia, *Persia*, Ireland, and the temperate parts of Asia and North America.

GINGER, West and *East Indies*, and Sierra Leone.

INDIGO, India, West Indies, Mexico, Brazil, Egypt.

LEMON, Portugal, countries on the Mediterranean, *India* and *Brazil*.

LOGWOOD, Central America, West Indies, and *Mexico*.

MAHOGANY, West Indies, South America.

MANIOC, West Indies and Africa.

NUTMEG, East and West Indies, Brazil.

OLIVE, Syria, and other Asiatic countries, and south of France.

OPIUM, Asiatic Turkey, Egypt, India, and Persia.

ORANGES, Spain, Portugal, Malta, Sicily, Azores.

PEPPER, India, Further India, Eastern Archipelago.

PINEAPPLE, West Indies.

POTATO, Europe and *America*.

RAISINS, Asiatic Turkey and Spain.

RHUBARB (Drug), Thibet, Chinese Tartary.

RICE, Southern States of North America, south-east of Asia, Japan, India, China, Egypt.

ROSEWOOD, South America.

SAGO, Ceylon, India, Borneo, Singapore.

SUGARCANE, East and West Indies, Brazil, India, Mauritius,

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* The names printed in italics are the names of the countries of which the plants are native.

Demerara.

SUGAR MAPLE, United States, British North America, *Canada.*

TEA, *China, Assam.*

TEAK, East Indies, Africa, and India.

TOBACCO, *United States*, Germany.

WALNUT, North America, the Himalayas, and south of Europe.

WHEAT, United States, Russia, Germany, British North America, France.

WINES.—Spain, Portugal, France, Hungary, Germany, &c.

YAM, East and West Indies, *Ceylon.*

141. Animals: Their Geographical Distribution.—It has been estimated that the total number of known species of animals, including *insects*, is 250,000, or about 50,000 if we take away the host of *protozoans* (which are mostly microscopic) and *insects*. Out of this number the *vertebrates*—that is the mammals, birds, reptiles, and fishes—equal very nearly 20,000. This is the only division which needs our attention now.

Like plants, animals have their particular zones, being influenced by *climate* and *food*, which also depend upon the climate; but, owing to their power of locomotion and dispersion, their limits are not so easily fixed, and are less precise than those of plants. Still there exists a similar horizontal and vertical arrangement of animal forms. The *fauna* of the tropics is more exuberant in numbers, size, strength, and beauty than that of the temperate zone, which in its turn excels the Arctic and Antarctic regions, with the exception of marine animals and sea fowl, which are abundant in the latter regions. Arms of the sea and mountain chains also often separate the *fauna* of one part of a country from the other.

The world has been divided into seven zones or regions, according to the character of the animal life. They are—

(1) PALÆARCTIC REGION, including Europe, Tunis and Algeria, Northern Asia, Northern China, part of Mongolia, Japan, the deserts of Central Asia, Persia, Asia Minor, and Japan. The chief animals of this division are—MAMMALS: Bear, fox, wolf, badger, glutton, sable, lynx, monkey of Gibraltar, squirrel, hare, rabbit, rat, mouse, beaver, lemming, horse. ass, wild boar, stag, musk-deer, goat, reindeer, chamois, auroch, moufflon, hedgehog, mole, shrew, and bat. BIRDS: Vulture, buzzard, osprey, eagle, owl, falcon, kite, thrush, finch, wax-wing, crossbill, bee-eater, oriole, woodpecker, cuckoo, pigeon, partridge, grouse, quail, francolin, goose, swan, duck, gull, pelican, diver, puffin, flamingo, grebe, snipe, crane, bittern, stilt, spoonbill, and coot. This is the richest region of birds, Europe containing no less than 600 species. REPTILES: Frog, toad, newt, tree-frog. triton, proteus, common snake, viper, chameleon, lizard, gecko, turtle, and tortoise.

(2) ETHIOPIAN REGION, embracing the west, south-west, south-east, and north-east of Africa, Arabia, Madagascar, and the Mascarene Islands. MAMMALS: Bear, lion, leopard, jackal, fox, wolf, hyena, ratel, cheetah, squirrel, porcupine, hare, rat, mouse, baboon, gorilla, chimpanzee, lemur, antelope, gazelle, giraffe, Arabian camel, zebra, eland, gnu, ibex, addax, rhinoceros, boar, hippopotamus, and elephant. BIRDS: Vulture, eagle, falcon, owl, hoopoe, waxwing, colic, hornbill, oriole, parrot, cuckoo, honey guide, pigeon, guinea fowl, quail, ostrich, crane, bittern, ibis, snipe, adjutant, albatross, and pelican. REPTILES: Crocodile, lizard, gecko, land tortoise, frog, lepidotis, coccilia, and cobra.

(3) INDIAN REGION, which embraces British India, Central and Southern China, Burmah, Siam, Cochin, Malaysia, the Nicobar and Andaman Islands, East Indies, and the Philippine Islands. MAMMALS: Monkey, ourang-outang, flying lemur, fox, bat, shrew. banxring, bear, lion, jackal, wolf, leopard, tiger, cheetah, squirrel, hare, rat, mouse, antelope, buffalo, yax, zebu, sheep, goat, gazelle, ibex, hog, wild boar, rhinoceros, elephant, tapir, phalanger. BIRDS: Eagle, vulture, osprey, kite, owl, falcon, hornbill, colic, bee-eater, hoopoe, sunbird, waxwing, bird of paradise, edible swallow, tailor bird, paroquet, woodpecker, cuckoo, lory, honey-guide, channel-bill, peacock, pheasant, francolin, mound bird, crane, bittern, snipe, adjutant, pelican, flamingo. REPTILES: Chameleon, dragon lizard, gecko, sea-snake, cobra, frog, coccilia.

(4) NEARCTIC REGION, including Greenland and North America, as far down as Mexico. MAMMALS: Puma, civet, wolf, bear, sea-otter, sable, lynx, dog, squirrel, hare, beaver, porcupine, rat, mouse, musk-ox, elk, bison, sheep, bighorn, prongbuck. BIRDS: Eagle, vulture, osprey, falcon, owl, turkey, thrush, humming-bird, mocking-bird, finch, waxwing, cedar-bird, crossbill, Carolina paroquet, cuckoo, raven, crow, pie, jay, woodpecker, quail, grouse, flamingo, goose, duck, albatross, diver, puffin, tern, grebe, pigeon. REPTILES: Alligator, tortoise, lizard, snapping turtle, rattlesnake, tropidonotis, bull-frog, triton, siren, proteus.

(5) NEOTROPICAL REGION, including Central America from Mexico to Panama, the Andes to Bolivia, the highlands in the basins of the Amazon and Orinoco, Guiana, S.E. of Brazil, Paraguay, Chili, La Plata, Patagonia, the West India Islands or Antilles. MAMMALS: Bear, puma, jaguar, racoon, coati, kinkajou, squirrel, hare, porcupine, cavies, chinchilla, agouti, rat, mouse, monkey (including those with prehensile tails, as marmosets and sajous), bat, vampire, ant-bear, ant-eater, armadillo, llama, alpaca, gauruti, guanaco, vicuana, tapir, peccary, opossum, yapack. BIRDS: Condor, vulture, kite, owl, caracara, humming-bird, umbrella-bird, trogon, bell-bird, plant-cutter, boat-tail, creeper, cuckoo, cockatoo, parrot, toucon, macaw,

avis, turkey, quail, curassow, spoonbill, ibis, trumpeter, adjutant, flamingo, penguin, grebe, petrel, tropic bird. In this region it may be mentioned that upwards of 400 species of *humming-birds* are to be found, and of the splendid tanagers 193 out of the 222 known species belong to South America. **REPTILES**: Alligator, lizard, boa, rattlesnake, turtle, lepidotis, coccilia, tree-frog, toad, and iguano.

(6) **AUSTRALIAN REGION** consists of Australia and the eastern half of the Malayan Archipelago up to Wallace's line. The chief animals of this region are the pouch-bearers. There are neither monkeys, cud-chewers, or thick-skinned animals. **MAMMALS**: Kangaroo, wombat, phalanger, koala, pouched-wolf, dasyurus, banded ant-eater, echidna, and ornithorhynchus (a mole-shaped animal with a jaw like a duck's bill). **BIRDS**: Parrots, cockatoos, and grass-paroquets are numerous; the cuckoo, woodpecker, bower bird, thrush, lyre bird, oriole, honey-eater, emu, falcon, black swan, and goose. **REPTILES**: Snakes, landosca, lizards, moloch, tortoise, and gavial.

(7) **PACIFIC REGION**, New Zealand, Polynesia, &c. Very few animals inhabit this zone, the only ones being bats. Birds are plentiful, and include parrots, paroquets, honey-eaters, finches, plumed birds, the apteryx of New Zealand (wingless), lory, tropic bird, and coot. **REPTILES**: Turtle, iguana, lizard, sea-snake, &c. This latter region is sometimes joined to the Australian.

Animals Peculiar to Certain Regions.—Each quarter of the globe has its own class of animals preponderating. Europe and Asia have the ruminantia; Africa, land tortoises; North America, birds of passage; South America, the edenta, or *toothless* animals; Australia, marsupialia, or *pouched* animals. In many cases they are confined to their own country. For instance, the reindeer and hamster are confined to the very north of Europe; the chamois and ibex, the Alps; the aurochs, the Caucasus and crown forests of Russia; the marmot, the Alps and Pyrenees; the kangaroo and ornithorynchus, to Australia, in which country the three great orders of animals are entirely wanting—namely, the *ruminantia*, or those that chew their cud, as the ox, sheep, &c.; the *pachydermata*, thick-skinned animals, like the horse, elephant, &c.; and the *quadrumana*, or four-handed animals, such as monkeys, apes, &c. The hippopotamus and giraffe are confined to Africa; the camel to the dry deserts of Africa and Asia; the tsetse (an insect whose bite is death to certain animals) is often confined to the regions lying on one side of a river, in different parts of South Africa; the hyena, quagga, and Cape buffalo to South Africa. The true humming-birds, some of which do not weigh more than 20 grains when alive, entirely belong to South America, also the llama, alpaca, ocelot, prehensile-tailed monkey, the condor, the rhea, and the hang-nests. The cashmere goat, musk-deer, panui sheep, are common to Central Asia;

the royal tiger, to Southern Asia. Among the marine animals, the right whale, seal, and walrus are confined to the Arctic Sea; the sperm whale is never found out of the tropical parts of the Pacific. The coral insects only exist in tropical and sub-tropical regions; and the herring, cod, salmon, &c., only reach perfection in the colder seas.

142. Representative Species.—Some animals of the Old World, though not appearing in the New, may be said, roughly, to be represented by species in many points similar. Thus, the camel of the Old World is represented by the llama and alpaca of the New, their habitat being nearly the same as the camel; the lion and tiger of the Old are represented by the puma and jaguar of the New; the ostrich of Africa by the rhea of South America and the emu of Australia; the crocodile of the Nile by the gavial of the Ganges and the alligator or cayman of the Amazon and Orinoco.

143. Distribution of Marine Life.—Professor E. Forbes sketched a scheme of *Bathymetrical* distribution—that is, distribution in depth, arranging the ocean into four zones. (1) The *Littoral Zone*, lying between high and low water marks, and characterised in our own seas by such shellfish as periwinkle, mussel, cockle, limpet, razor-shell, &c. (2) The *Laminarian Zone*, extending from low-water mark to the depth of 15 fathoms, and including such fish as the star-fish, sea-urchin, tubularia, modiola, and pullastra. (3) The *Coralline Zone*, in which the corals, &c., are the typical inhabitants, extending from 15 to 50 fathoms, and characterised by the disappearance of ordinary sea shells, but abounding in buccinum, fusus, venus, pecten, &c. (4) The *Deep Sea Coral Zone*, extending to 100 fathoms and more; containing brachiopod mollusca that cannot exist in shallower waters, cidares, &c.

That marine animals can exist at great depths of the ocean is fully proved by the Challenger expedition of 1873-76, which, during its explorations and dredging operations, brought up multitudes of living creatures (many of which were unknown before) from the depth of three miles or more.

Horizontal Distribution.—The fishes and shellfish of the tropics are noted for their varied and brilliant tints; while those of the Arctic Seas are of uniform and sombre hues. The right whale is not found beyond the cold waters of the higher regions in either hemisphere, the sperm whale keeping to the tropical areas of the Pacific. The seal and walrus also keep to the colder, temperate, and Arctic regions. The cod, herring, haddock, salmon, &c., thrive best in the colder waters of the higher latitudes. The shark prefers the waters of the torrid zone, and the coral builders only exist within the tropical and sub-tropical regions.

DISTRIBUTION OF MAN.

144. Man is more capable of adapting himself to any climate than any other animal, being able to live under extreme degrees of heat and cold, and on a greater variety of food. The next to man in both these respects is the dog, his faithful companion and friend. Though man can adapt himself to different climates, yet he is, in common with the other animals, influenced by external circumstances, but in a less degree.

Though there are what are termed different *races* of men, yet there is but one *species*, the different races being only different varieties, the diversities having arisen from the long-continued action of climate and other external influences. In a similar manner the difference in *species* or *varieties* of other animals that have in succession inhabited this globe may be considered as the *result of the gradual modification of pre-existing species;* and so also with the plant life of the globe. This is what is termed the *doctrine of evolution.*

145. Classification of Races.—There have been several different classifications put forth, one of which until lately obtained great currency, viz., Blumenbach's, which divided them into five divisions: (1) the *Caucasian*, (2) *Mongolian*, (3) *African*, (4) *American*, (5) *Malay;* but the most modern classification is into three primary races—the Caucasian, or white and bearded race; the Mongolian, or tawny and beardless race; and the Negro, or black-skinned and woolly-haired race.

Caucasian, or White Race, with straight oval face, large broad forehead and skull, narrow nose, small mouth, thin lips, large eyes, tall in stature, and very intellectual. They occupy nearly all Europe, South-Western Asia, Northern Africa, and extend from Iceland to the Ganges, and from the Tropic of Capricorn to the Arctic Circle.

Mongolian Race.—Head nearly round, but narrow at the top, and low forehead; broad flat cheek bones, which are also prominent; yellow skin, stature short, eyes obliquely set, and next in intellect to the above race. This class includes all the rest of Asia and Europe not included in the Caucasian.

The Negro, or Ethiopian Race.—Narrow head, elongated backwards; narrow convex forehead, low and retreating; nose broad and flat, projecting jaws, under teeth turned obliquely forward, thick lips, crisp and woolly hair, and skin black. They occupy the whole of Continental Africa, south of the Tropic of Cancer. The true Negro is confined to the district between the Desert of Sahara and northernmost border tribes of the Hottentots and Kaffirs in South Africa.

In addition to the above there are several minor varieties, which may be regarded as modifications and an intermixture of the three primary races. They are the *Malays*, in Malaysia and Madagascar; the *Papuans*, in New Guinea, New Hebrides, &c.; the *Maoris* of Australia and New Zealand; and the *American* or *Red Indians*, the aborigines of North and South America. These may be regarded as Mongolians.

146. Huxley's Classification.—Professor Huxley divides them into two varieties, according to the character of the hair. (1) The *Ulotrichi*, having crisp or woolly hair. (2) The *Leiotrichi*, having smooth hair. The first race (1) varies in colour from yellow and brown to the darkest colour of human skins, termed black, and they are *dolichocephalic*;"* that is, their skulls are longer than broad. This class includes the Negroes, Bushmen, and Malays. Class (2), the Leiotrichi, is divided into four divisions—viz., the (*a*) *Australoid Group*, with dark skin and eyes, long wavy black hair, dolichocephalic skulls, with well-developed brow ridges, broad nose, and heavy projecting jaws. This group includes the natives of Australia and the coolies. (*b*) The *Mongoloid Group*, with yellowish or reddish brown skins, black eyes and hair. It includes the Chinese, Japanese, Tartars, Polynesians, Esquimaux, and American Indians. (*c*) The *Xanthocroic Group*, of fair, white, clear skin, grey or blue eyes, includes the Slavonians, Teutons, Scandinavians, and fair Celtic speaking nations. (*d*) The *Melanochroi*, or dark whites, with pale complexions, dark eyes and hair, includes the Iberians, black Celts of Western Europe, dark-complexioned whites of the Mediterranean, Western Asia, and Persia. This group is probably a mixture of Australoids and Xanthochroi.

Man's influence on the life of animals may be noticed in two ways especially. (1) In *preservation*, as in the case of the horse, ox, dog, and other animals, which man domesticates as well as preserves, making them useful companions. (2) *Extermination*. Such animals as are dangerous to man, or destructive to his property, are speedily exterminated, or driven out to less frequented spots; as, for instance, the wolves and bears of England, which have been long exterminated—other animals are also exterminated by the great demand

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*Skulls are called *dolichocephalic* when the breadth is less than four-fifths of the length, and *brachycephalic*, when more than four-fifths.

for their skins—others in the chase. The influence of man may also be noticed in transferring animals from their own region to another; as, for instance, the domestic animals—horse, sheep, dog, &c.—have been taken by man into nearly all the habitable regions of the globe. The horse has probably been brought from Asia to our own country; but the dog is the only animal that can adapt itself to all climates, like man. Many animals, as the camel, reindeer, &c., cease to exist away from their own particular habitat.

The Population of the Globe.—According to the latest authorities the population of the different continents is as follows: Europe, 309,178,300; Asia, 824,548,500; America, 85,518,800; Africa, 199,921,600; and Oceanica, 20.000,000 (of which Australia has 5,000,000); making a total of 1,439,168,200 persons.

THE ELEMENTS OF PHYSIOGRAPHY.

PART II.

LIGHT.

147. Theories Concerning the Nature of Light.—Regarding the nature of the light and heat transmitted to us from the sun two theories have been advanced, namely, the *emission theory* and the *undulatory theory*. The former, which is generally attributed to Sir Isaac Newton, supposes light to consist of infinitely small luminiferous particles of matter, emitted with exceeding celerity, capable of producing light and heat when they strike against bodies. This theory has given way to the latter, or *undulatory theory*, which assumes that there exists ever in space, and between the particles or molecules of all matter, an exceedingly rarified, highly elastic substance, termed *ether*, which is 39,000,000 times thinner and 1,278 times more elastic than air, and that it is to the undulations and vibrations of this substance that we owe the phenomena of light and heat, the light being produced by the action of luminous bodies upon the ether, and the heat by the vibrations of the particles of a body, each particle being supposed to have a motion either backwards or forwards, but so rapid that the eye is unable to perceive it. The more rapid the motion the greater the heat. This ether, when excited by the presence of hot and luminous bodies into undulations, produces impressions of light and heat on bodies that encounter the waves.

148. Propagation and Velocity of Light.—Light, as previously stated, is the result of *wave motion*, the waves being of extreme minuteness and propagated in straight lines at the rate of 186,000 miles per second, the vibration of the ether taking place at right angles to the direction of propagation. The velocity of light was first determined by Römer, a Danish astronomer, from observations on the eclipses of Jupiter's satellites. He observed the periods of these eclipses were found, when the earth was between Jupiter and the sun, to take place 8 minutes 13 seconds earlier than the calculated time. and just as much later when the earth was on the opposite side of her orbit. This difference he properly accounted for by supposing that such was the interval of time taken by light in travelling over half the earth's orbit, which is our distance from the sun.

The velocity was also deduced by Bradley from the *aberration* of light. He observed that a star, whose position in the heavens he could previously calculate, could not be seen by a telescope, if pointed directly to the spot indicated, unless a certain slope were given to it. Thus, if a star were in the zenith, it could not be seen by the telescope held vertically. This result is owing to the combined effect of the earth's motion in her orbit and the passage of light from the star. He found that the telescope had to be moved through an angle of 20·445″ from its vertical position before the star could be seen. This is called the *constant of aberration.* Knowing this angle, the earth's speed in her orbit, and the distance from the earth to the sun, the velocity of light may be calculated; and, *vice versa*, by knowing the velocity of light, the earth's speed in her orbit, and the *constant of aberration*, the sun's distance may be determined.*

149. Reflection.—Light in itself is invisible. Objects are rendered visible in consequence of their powers to *reflect*, or *scatter* the light which falls upon them in all directions. If the ray of light fall perpendicularly upon a plane surface, it is reflected directly back again, but, if at a certain angle to the normal, or perpendicular, it will be reflected back at the same angle but on the other side. This is expressed in the general law—the angle of incidence is equal to the angle of reflection.

150. Refraction.—Regarding the rays of light, though they proceed in straight lines, yet on passing out of a rarer into a denser medium they are generally *bent* or *refracted* out of their course. If the ray falls on the surface of the medium perpendicularly, it suffers no refraction, but if it strikes the surface obliquely, it is refracted more or less according to the greater or less density of the air. For instance, when a ray passes from air into water it is refracted *towards* the perpendicular; and conversely, when it passes from water into air it is refracted *from* the perpendicular.

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* From the velocity of light, it may be found by a very simple calculation that the earth's velocity in her orbit is about 18½ miles per second. Hence the circumference of her orbit = 18½ miles × 365¼ × 24 × 60 × 60 ∴ radius = this divided by 2 × 3·1416 = $\frac{583815600}{2 \times 3{\cdot}1416}$ = 92,220,000 miles = mean distance of the sun from the earth.

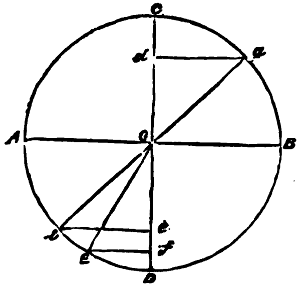

Fig. 5.

To understand the law of refraction. Describe a circle A C B D, with radius O C, A B representing the surface of water, and C D perpendicular to it. Then if *a* O be a ray of light coming from *a* and entering the water at O, it will not proceed in the straight line *a* O *b*, but will be bent towards the perpendicular and reach *c*. Draw *a d*, *b e*, *c f*, perpendicular to C D, then *a d* and *c f* represent the relation between the angle of incidence and the angle of refraction, thus in the case of water, *a d* would be represented by 4, and *c f* by 3, as the index of refraction for water is $\frac{4}{3}$. For air and glass the index is $\frac{3}{2}$. This relation is expressed by the following law.—*That for the same media the sine of the angle of incidence is always proportional to the angle of refraction.*

A familiar example of this phenomenon is noticed in the case of a stick, partially immersed in a basin of water, appearing broken at the surface of the water, and the part below seeming higher than it really is. A similar occurrence takes place when the sun's rays enter the atmosphere of this earth, some being reflected back while the remainder are refracted downwards towards the earth (See "Atmosphere—Twilight"): but the further they advance through the atmosphere the more they are bent, owing to the density of the air continually increasing, so that the rays when they have arrived at the earth's surface have travelled through a parabolic curve. The tangent to this curve at the surface of the earth is the direction in which the celestial object appears, causing the sun and other heavenly bodies to appear higher in the heavens than they really are. Hence, in calculating the angles taken in measuring the distance and size of the sun and other heavenly bodies, notice must be taken of refraction. Thus when the apparent zenith distances have been observed with the mural circle, they must be corrected by the addition of the refraction.

151. The Limiting Angle.—We stated, just previously, when a ray passes from a *rare* into a *dense* medium it will *generally* be refracted; but conversely, a ray cannot pass from a *dense* into a *rare* medium, if its angle of incidence exceeds a certain degree—this is termed the LIMITING ANGLE. For water and air this angle is 48½°. Thus in Fig. 5, if *b* O be the incident ray, then if the angle *b* O D = 48½°, the refracted ray will emerge in the direction O B, or parallel to the surface of the water. If the angle *b* O D be greater than 48½° the ray is *wholly* or *totally* reflected. It is upon this principle that the *mirage* depends.

Thus it sometimes happens that ships appear as if painted in the sky and not resting upon the water, or rocks and sands appear raised above the surface. These phenomena are due to the varying density of the different layers of the atmosphere lying near the surface of the earth, and occur when the atmosphere is warmer than the surface of the sea, the density of the successive layers diminishing upwards owing to their contact with the surface of the sea. The rays of light from an object, as a ship for instance, in passing through them are refracted from the perpendicular, and at length becoming incident at angles greater than the *limiting* angle are totally reflected, at certain points, and in returning through the strata they become gradually bent towards the perpendicular, and enter the eye of an observer as if they came from an object in the air.

When a ray of light passes obliquely through a plate of glass with parallel surfaces, it emerges in a direction *parallel* to the incident ray, being as much refracted towards the perpendicular on entering, as it is refracted from it on passing out. Even if the media be of different material the emergent ray would still be parallel to the incident ray.

152. Prisms.—A prism in optics is a wedge-shaped transparent substance constructed generally of glass. The angle enclosed by the two oblique faces is called the *refracting* angle of the prism. When a ray of light enters a prism it is refracted upwards, that is, *toward* the perpendicular, and on emerging from the prism it is refracted *from* the perpendicular. The angle between the emergent ray and the incident ray is the angle of deviation. It is found that *the deviation is always towards the thickest part of the prism.* When the angle of emergence and the angle of incidence are equal, the deviation is a minimum.

153. Lenses.—Any portion of a refracting medium which has two opposite surfaces, either both curved or the one plane and the other curved, is termed a lens. Lenses are of two classes, *converging* and *diverging*, each class comprising three kinds. The converging ones are the *double convex*, with two convex surfaces, the *plano-convex* with one convex surface, and the *concavo convex*, or *meniscus*, with one concave and one convex surface, the convex having the greater curvature. The diverging ones are the *double concave*, with two concave surfaces, the *plano-concave*, and the *convexo-concave*, the *concave* surface having the greater curvature. When parallel rays fall upon a converging lens—as, for instance, on a double convex one—they converge to a point, This point is called the *principal* focus—that is, it is the focus of parallel rays. When they fall on a diverging one—a double concave one, for instance—the rays are caused to diverge, as if they came from a point on the same side of the lens on which the light falls. This point is therefore the *principal* focus.

If an object is placed before a double convex lens, *beyond* the principal focus, the rays will meet and form a real inverted image of the object. If the object be placed *between* the lens and the principal focus, a magnified and erect image will be formed. Such an arrangement as this constitutes the simple microscope. The *compound* microscope consists essentially of two glasses; the one next the object is called the *object* glass or *objective*, the other the *eye* glass, or *ocular*.

When white light passes through an ordinary glass lens there is a certain amount of dispersion, so that the image of an object is seen with a coloured border. This is called chromatic aberration. To remedy this defect an arrangement of prisms, or lenses with different refracting angles, and formed of substances with varying dispersive powers, is used; thus, for instance, a double convex lens of crown glass is combined with a concavo-convex of flint glass. This is termed an *achromatic* lens. The effect of the second lens is to reblend the coloured rays which the first has produced, and at the same time such an amount of refraction is preserved as to bring the light to a focus. An object glass provided with achromatic lenses is termed an *achromatic object glass*.

154. The Telescope.—Of all the instruments used in the scientific investigation of the heavenly bodies the chief and foremost is the telescope—an instrument used to magnify objects, or to present their images under a larger angle than the objects themselves subtend, and likewise to render objects visible which would otherwise be invisible.

The simplest form of an astronomical telescope consists of a double-convex lens, placed at one end of a tube, six inches longer than the focal length of the lens. An image then appears in the air, within the tube, six inches from the end where the eye is placed, and is seen as a new object.

The apparent size of an object is magnified when, instead of the object itself, we view the image formed by a lens. For instance, if the object viewed was distant 6,000 feet, and the focal length of the lens 6 feet, the image will be to the object as 6 : 6,000—that is, 1,000 times less; but as this image may be considered as a new object viewed by the eye at a distance of 6 inches, the smallest distance at which we can obtain distinct vision, instead of 6,000 feet, the angle under which it is seen is greater, and also the image is as much larger when seen at 6 inches, as 6,000 feet is to 6 inches or half a foot = 12,000 times; but it is 1,000 times less than the object. Hence it is equal to the object divided by 1,000 and multiplied by 12,000, or 12 times as large as the object, so that its entire surface is increased $12^2 = 144$ times.

The above is a *refracting* telescope. We will now describe the *reflecting* telescope, of which there are four kinds—the Newtonian, the Gregorian, the Cassegrainian, and Herschelian.

The *Newtonian* consists of a concave object-speculum or mirror, a plane reflector, making an angle of 45° with the axis of the telescope, placed between the object-speculum and its focus, and an eye-piece. The pencils of light from an object at a distance tend to form an image after reflection at the object-speculum, but are bent by the plane reflector, so that it is formed on the axis of the eye-piece and in the focus of the eye-lens.

The *Gregorian* telescope consists of a large concave mirror, containing an aperture in the middle and placed within a tube; a smaller concave mirror is fixed in the axis of the larger and at a distance from it, equal to a little more than the sum of their total lengths. Near the end of the smaller tubes are two plano-convex eye-lenses, with the plane side towards the eye. The pencils of light proceeding from a distant object, after reflection at the object-speculum, form an inverted image of the object at the focus of this speculum, and after reflection again at the small speculum, form a second image inverted with respect to the former, and erect with respect to the object.

The *Cassegrainian* telescope has a small convex instead of concave mirror, which is placed at a distance from the larger mirror, equal to the difference of their focal length.

The following is a convenient way of ascertaining the magnifying power of reflectors: *Multiply the focal distance of the larger mirror by the distance of the smaller one from the image; also multiply the focal distance of the small mirror by the focal distance of the eye-glass; then divide the greater of these products by the lesser, and the quotient is the magnifying power.*

The telescopes of Herschel and of Lord Rosse dispense with the smaller mirror by inclining the larger one slightly, so as to throw the image on one side, when it is viewed by the eye-glass. They are the two largest that have been constructed. Of Sir W. Herschel's the diameter of the speculum, or mirror, was 4 feet, its weight 2,118lb., and its focal distance 40 feet. The diameter of the speculum of Lord Rosse's is 6 feet, and its focal distance 56 feet, diameter of the tube 7 feet, and the weight of the tube and speculum more than 14 tons, the speculum being 4 tons. The cost of this instrument was £12,000.

Another optical instrument of great value is the *microscope*, an instrument for magnifying minute, but accessible, objects. A single microscope consists simply of a convex lens, commonly called a magnifying glass, in the focus of which the object is placed and through which it is viewed.

The *solar microscope* is a microscope with a mirror attached to it on a movable joint, which can be adjusted so as to receive the sun's rays and reflect them upon the object. It consists of a tube, a mirror, and two convex lenses. The rays of the sun are reflected by the mirror through the tube upon the object, the image of which is thrown upon a white screen placed at a distance to receive it.

Of the other optical instruments, only one needs mention here, and that is the *spectroscope*, an instrument which reveals to us the nature and constitution of the heavenly bodies.

155. The Spectroscope is an instrument used for the purpose of analysing the rays of light from any luminous source. It consists chiefly of a series of prisms constructed of flint glass, to cause the beams of light to be dispersed. The more recent construction is to have a prism of crown glass, then a prism of flint glass, and so on, leaving a crown glass one last. This arrangement causes a minimum of deviation in the dispersed beam. The prisms are generally so arranged, so that the axes of three telescopes mounted on a stand, converge towards them. One of these telescopes is so arranged that the rays of light from the flame viewed fall upon a lens in it and converges to a point within a tube, namely, the principal focus of the second lens, and therefore issue from the tube in parallel rays, falling upon the prisms. The light on leaving these is decomposed, and enters the observing telescope. The spectrum forming are inverted, which is magnified by the occular. The remaining telescope is provided with a micrometer for measuring the relative distances of the lines of the spectrum.

One of the simplest forms of telescope is one manufactured by Messrs Browning. It consists of seven prisms arranged in straight lines, dovetailed into one another and enclosed in a tube three and a half inches long.

PLANETARY MOTION.

156. Planets.—It has been determined by astronomers that the earth we live on is one of a number of *planets* (wanderers) which revolve round the sun as a common centre, but at different distances and velocities. These, with their *satellites*, or moons, together with an unknown number of comets, constitute what is termed the solar system.

There are at present known eight large or primary *planets*, which revolve round the sun in nearly circular *orbits* or paths, and 246 *asteroids*—small planet-like bodies, which are all situated between the orbits of Mars and Jupiter, and are supposed to be fragments of an ordinary-sized planet that has been disrupted. All the planets between the sun and this gap are called *inferior* or *interior* planets, and those beyond *superior* or *exterior* planets. There are 20 secondary planets, or moons, revolving round their primaries ; and an unknown number of comets, which revolve round the sun, but move in no fixed direction. The primary planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune, their names being written in the order of their nearness to the sun. Of the secondary planets, or moons, the Earth and Neptune have one each, Mars two, Jupiter and Uranus four each, and Saturn eight. The multitude of stars that move in a mass and keep their position with regard to each other, and to the sun, moon, and a few others, are called fixed stars.

157. Form and Motion of the Planets.—The planets are all round bodies (*spheres*, or more correctly *spheroids*, like the earth, owing to the effect of centrifugal force—that is the force which causes all matter when spinning round to have a tendency to fly off in a straight line). They have two motions. First, their motion round the sun, and secondly, their revolutionary motion on an axis, travelling in both cases from west to east, each revolution being termed a day. The paths or *orbits* that they describe in their journey round the sun are elliptical—that is, the figure described is an ellipse,[*] though differing very little from a circle, or having very little eccentricity.

The cause of the planets moving in elliptical paths is the result of *two forces* acting on the planet at the same time, but in different directions. These forces are the *centrifugal* (or *tangential*) and the *centripetal*. The former would, if not counterbalanced by some other force, cause the earth to move right away from the sun, but this is balanced by the centripetal force, which always acts at right angles, proceeding from the attraction of the sun. This force, if also unopposed, would by the *laws of gravitation* cause the planet to move towards the sun with a continually accelerated speed. But with the two forces acting on it at the same time it obeys neither, following, according to the *parallelogram of forces* (7, 8), a mean course, describing a curved path, which in all cases is one of the conic sections, its shape depending on the direction, distance, and velocity.[†]

In the annexed figure let A represent the earth, and S the sun; then, supposing the earth to be moving in a straight line, with a velocity sufficient to carry it to T in a given time, during which the sun's attraction acts upon A with sufficient force to bring it to E, the earth will describe the diagonal of the parallelogram ATRE, though it does not pursue a straight line, as in Fig. 1, page 9, but a *curve*, owing to the sun's power of attraction acting continually on the earth, and thereby causing a deviation from the right line. In an exactly similar manner the earth performs the curve, RV. To understand more correctly how it is that the line is not a right line, it must be remembered that the attraction of the sun is not exerted at once, or by a single impulse, but by degrees, being constant. Hence we may suppose that the parallelogram ATRE is made up of an infinite number of minute parallelograms, and that the *curved line* likewise consists of an infinite number of diagonals.

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[*] An ellipse is a plane figure bounded by a curved line, and is such that if from any point in the curve, two straight lines be drawn to two certain points, the sum of these lines will always be the same. These two points are called the foci of the ellipse, and the distance from the centre of the ellipse to either of its foci is called the *eccentricity*.

[†] Let d=diameter of the circle; a, the centrifugal force; b, the centripetal; v and v_1, their respective velocities; then the path is a *circle* when $v^2=d\times v_1$; an *ellipse*, when $v^2>$ (is greater than) $d\times v$; a *parabola*, when $v^2=2\ (d\times v)$; an *hyperbola*, when $v^2>2\ (d\times v)$. In every case the angular velocity of the *radius-vector* must be inversely proportional to the square of the mutual distance of the two bodies.

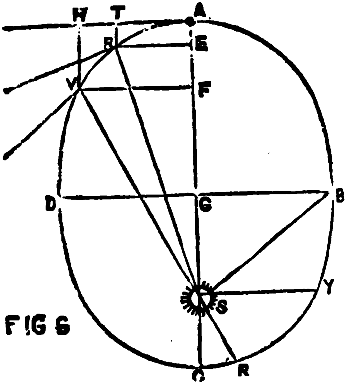

FIG 5

In the annexed figure A B C D A represent the orbit of a planet. S. the sun situated is one of the foci. F being the other or unoccupied forms of the ellipse. A C is the major and B D the minor axis. C, the point at which the planet is nearest the sun, is called the *perihelion* of the orbit, and A, the point when it is most distant, is called the *aphelion*. Any line joining the sun to the planet, as S R. S V is called the *radius vector* of the orbit. G is the centre of the ellipse, and G A the *semi-major axis*, or mean distance. The *eccentricity* of an ellipse is its deviation from a circle, and is expressed by the ratio of S G to C G. The line A C is also often called the line of *apsides*.

We are now in a better position to understand the three simple laws discovered by Kepler—and hence called Kepler's laws of elliptic motion. These laws are :—

(1) *That every planet moves so that the radius vector, or line drawn from the sun, describes about the sun areas proportional to the times.*

(2) *That the planets all move on elliptic orbits, of which the sun occupies one of the foci.*

(3) *That the squares of the time of the revolutions of the planets are as the cubes of their mean distances from the sun.*

According to law (1) if the areas S R V, S Y R_1, and B Y S are equal to one another, then the planet will describe the areas R Y, R_1 Y, and Y B in equal periods of time, hence its *velocity* is *greater as its distance from the sun is less.* We have thus the means of tracing the position of a planet in its orbit. Law 3 is a very important one. It furnishes the law which regulates the times and distances. It furnishes us with a proportion by means of which we are able to determine the distance of the sun. Thus, knowing the periodic times, or length of times required for the Earth, Venus, or other planet severally to move round the sun, we find by calculation that if the distance of the earth from the sun be taken as 10· the distance of Venus must be 7·2, and Mercury 3·8. The second and third of these laws are natural consequences of the universal law of gravitation (see 15), and the first has been proved by Newton to follow the simple laws of motion, and proves the sun the centre of attraction for each of the planets.

Most of the planetary orbits lie very nearly in the plane of the ecliptic, but a little inclined to it, hence the planets are always found in a narrow zone of the heaven called the *zodiac.* This zone of the visible heaven extends in breadth to certain equal distances on both sides of a great circle of the celestial sphere in the plane of the ecliptic, or of the earth's orbit produced. This circle makes with the plane of the earth's equator an angle equal to about 23° 27′ 35″. It is divided into twelve equal parts called *signs*, which are named after the figures intended to designate the groups of stars about it.

Nodes.—The two opposite points where the orbit of a planet seems to intersect the ecliptic. The moon when travelling from south to north passes through a point of the ecliptic. This is termed the *ascending node,* and the point of the ecliptic through which it passes when travelling from north to south is called the *descending node.* The line joining the nodes, in the case of the planets, must necessarily pass through the sun. This line is called the line of the nodes. These nodes are not to be regarded as fixed. They have a considerable proper motion from east to west, in process of time moving right round the ecliptic. Thus the lunar nodes shift their position in a year in a west direction to the extent of 19° 20′ 19·7″, so that the node would take $(360^\circ \div 19\frac{1}{3}) = 18\frac{1}{2}\frac{8}{9}$ years nearly to move round the ecliptic.

Elements of the Orbit.—To be able to follow the motions of a planet in her orbit, the following elements are necessary:—

(1) The form and magnitude of the ellipse must be known, that is, its eccentricity and the length of the semi-axis major.

(2) The position of the planet must be known at some particular time, and its mean daily orbit.

(3) The position of the plane in which the orbit lies must be known, that is, its inclination to the ecliptic and the longitude or position of the ascending node.

(4) The position of the ellipse in that plane must be known, or the longitude of the perihelion.

The elements once found, the position of the planets can either be calculated in advance, or carried back into the past.

THE FORM AND SIZE OF THE EARTH.

158. The Form and Size of the Earth is nearly that of a globe or sphere, or more correctly an *oblate spheroid*, being flattened at the poles, probably through the effect of its centrifugal force.

Among the many proofs put forth regarding the rotundity of the earth may be mentioned : (1) A vessel sailing away from the land does not become lost from view on account of its distance, but gradually sinks out of sight; first losing sight of her hull, next her lower or main sails, and lastly her top sails, thus showing that she is passing over a convex surface. (2) By employing a surveyor's level upon the surface of the water of a canal it will be found that at the distance of one mile the water is depressed below the level of the instrument about 8 inches, which is called the *dip*. This not only proves that the earth is round, but also gives the diameter of such a globe that will have a curvature equal to this, namely, 7,920 miles,* which is not very far from the mark, the true dip being 7·9821 inches. (3) In travelling any considerable distance, either north or south, new stars gradually appear in the direction in which the person is travelling, and those behind disappear. This is exactly what would happen if the earth was round, and under no other circumstances, hence we conclude the earth *must be round*. (4) The shadow cast by the earth on the moon during an eclipse is always circular, which could not be the case unless the earth was round.

Supposing the earth to be a sphere, if any *arc of the meridian* be measured which bears a known proportion to the whole meridian circle, we shall obtain the magnitude of the meridian, and therefore the diameter of the sphere. For instance, Norwood, by measuring from London to York, found a degree of the meridian to be 69½ miles. Thus, he took the sun's meridian altitude at London near the Tower, and deduced the latitude 51° 30′, and also at York, where he obtained the latitude 53° 58′, or a distance of 2° 28′. He measured from London to York and found it to be 301,917 yards. Hence he found the length of a degree to be $(301,917 \times \frac{15}{37})$ yards = 122,398¾ yards = (a little over 69½ miles). Therefore the circumference, according to this calculation, was 122,398¾ × 360 yards = 25,077 miles, and the diameter 25,077 ÷ 3·1416 = 7,981 miles.

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* By a well-known property of the circle we have : 2 (the radius − dip) + dip : length of surface measured :: length of surface measured : the dip. Let x = number of feet in radius, then we have $2\left(x-\frac{2}{3}\right)+\frac{2}{3} : 1760 \times 3 :: 1760 \times 8 : \frac{2}{3}$: that is $\frac{4}{3}x - \frac{4}{9} = (1760 \times 3 \times 1760 \times 8)$ feet; hence $x = \frac{1760 \times 3 \times 1760 \times 3 \times 8}{1760 \times 4} = \frac{1760 \times 9}{4} = 3960$ miles ; ∴ diam. $= 3960 \times 2 = 7{,}920$ miles.

This is the principle upon which the size of the earth is determined, but the earth *not* being a perfect sphere, the degrees are not all of the same length, hence the above is *not* the correct diameter. To obtain the true diameter geodetical surveys have been resorted to, which we will now describe.

159. Geodetical Surveys.—Before describing the method of the geodetical surveys we shall first describe the *theodolite*, the chief and foremost of the instruments used. It is used for measuring horizontal angles, and consists, in its simplest state, of a pillar turning freely on a vertical axis, carrying, on outriders with Y supports attached, a telescope, mounted like a transit instrument, capable of being directed to any point. It has a graduated horizontal circle, parallel to the horizon, read by verniers carried by the vertical pillar. There is also a semicircular arc fixed to the Y, for taking the vertical angles, so that at the same time both the horizontal angles subtended by each of the two points observed with it, and the angles of elevation of the points from the point of observation, can be taken.

We cannot, it is evident, measure at once the whole surface of the earth, but we can measure by degrees tolerably large portions of its surface in various situations, and then, by calculation, the whole circumference and area; or, to find its circumference, a degree of latitude is measured—that is, the length of an arc of a terrestrial meridian, the latitudes of the extremities of which differ by one degree. Thus the difference of latitude of two places in nearly the same meridian is to be ascertained by celestial observations, and their distance by terrestrial measurement. A horizontal base line of a few miles in length is to be selected with great care over a level tract of country—as, for instance, the Lough Foyle base line, in Ireland. Accurately measured, this line then forms the basis for a large triangulation of the country to be surveyed. Conspicuous objects, on summits of hills, if possible, within sight, are then selected, and the angles which the lines joining them and the extremities of the *base* (viz., the measured line) make with its direction are accurately measured with the aid of the theodolite. Having two of the angles, the third angle may be found by adding these two together, and subtracting their sum from two right angles, or 180°. Now, we have all the data that is requisite for finding the lengths of the remaining two sides of the triangle, and hence its area, as, by knowing the angles of any triangle, we know their *relative or proportionate lengths*, so that when one side is known the other sides are easily calculated.[*] In surveying very large triangles on the earth's surface, and measuring each of the angles to avoid the slightest error, and also as a check to see if the two angles obtained are correct, it is always found that the sum of the three angles is *greater than two right angles*, which could not occur if the earth was a plane flat surface; but those of our readers who are conversant with spherical trigonometry know that this is always the case in all spherical triangles—the difference being a measure of the spherical area, known by the name of the spherical excess. Hence we have a proof that the earth must be a sphere. A series of triangles are measured across a country in the direction of a meridian, forming, as it were, a network on its surface. By these means a degree of latitude is measured, and from thence the circumference calculated. (For the latest results, see 62.) For the purpose of measuring the curvature of the earth, degrees of meridian at different latitudes have been measured. Now, if the earth was a perfect sphere it is evident that these degrees would be equal; but such is not the case. Hence the earth is not spherical. But the difficulty is to find the difference in the two diameters. The following is a very useful rule in determining the two diameters *approximately:* Having given the lengths of the arcs of the meridian corresponding to two given latitudes, divide each arc measured by the number of degrees and parts in it. Call the greatest quotient the first term, the other the second, and the difference is the third term. Then, to double the third term, add three times the second multiplied by the square of the sine of the latitude nearest the equator corresponding to the first term and divided by the square of the radius. From the sum subtract three times the first term multiplied by the square of the sine of the less latitude corresponding to the second term divided by the square of the radius. Call this result the fourth term. Then, as the fourth term : third term :: equatorial diameter : difference of the two diameters (equatorial and polar). Divide the third term by the fourth, and call the quotient the fifth term. Multiply three times the fifth term by the square of the least latitude corresponding to the first or second. To this add 1, and from the sum deduct twice the fifth term. Call this last result the sixth term. Then, as the sixth term : 2 :: first or second (according to which latitude has been used) : seventh term, which is the length of 2° on the equator. Multiply this by 57·29578, and the answer is the equatorial diameter. For the polar diameter diminish the equatorial one by the product of itself and the fifth term.*

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[*] Let *a* be the side measured, *b*, &c., the other sides; also let A and B be the observed angles; then the third angle (180°—A+B)=say C; then it is easy to prove by trigonometry that $b=\frac{a \sin. B}{\sin. A}$ and $c = \frac{a \sin. C}{\sin. A}$; both of which are adapted to logarithmic computation.

The results obtained of arcs measured in numerous places, as, for instance, those of Russia, France, India, Peru, the Cape of Good Hope, as well as our own country and other places, have been thoroughly investigated by the accomplished mathematicians, Airy and Bessel. They agree in giving the following as the true dimensions :—

Polar diameter............	7899·1 miles.
Equatorial diameter	7925·6 „
Mean diameter............	7912·35 „
Difference, or polar compression............... ..	26·5 „
Proportion of diameters	298 to 299 „

The circumference of the earth is 24,556 miles, the area of its surface, or superficial contents, 197 million square miles, and volume 259,000 million cubic miles.

The figure of the earth has also been investigated on the principle of hydrostatics. Considering the earth to have been originally a fluid mass, and taking the only force concerned to be gravity, Sir Isaac Newton came to the conclusion, from the consideration of this force, that the diameters were as 289 : 288.

160. The Density of the Earth.—Knowing the volume of the earth, all that is necessary so as to know the weight is to know the average weight of a cubic mile, or the mean specific gravity of its component matter. When we know the weight of the earth we have our only guide to the weight of any other planet. Various methods have been resorted to in order to estimate this density.

(1) *By observing the attraction exercised by a mountain on a plumb-line as compared with the earth's attraction.*

This depended on the principle that the relative masses of two planets are determined by noting their effects on a third, according to the law of gravitation (15) and (16). Here the earth itself is made one of the planets and a mountain the other, and the attracted body a plumb-line instead of a planet. The effect of the mountain is to deflect the plumb-line from the perpendicular. Thus it was found that Chimborazo caused a deviation of 11″, according to Bonguer and La Condamine, and according to observations made on Schiehallion, in Scotland, on opposite sides of the mountain, the sum of the deviations was 11″·6 ; and Sir H. James obtained a joint deflection of 4″·21, caused by Arthur's Seat, near Edinburgh, from which he calculated the specific gravity to be 5·316 as compared with water at 1.

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* The student should work the following example out for himself : The arc of meridian measured from lat. 30° to 31° is 68·878 miles, and the arc of meridian from lat. 45° to 46° is 69·047 miles. Find the diameters, and from thence the compression. *Ans.* E., 7925·15 ; P., 7799·25. Compression, $\frac{1}{285}$.

After the deflection is found the mountain must be thoroughly surveyed and the rocks examined, so that its specific weight as compared with water may be known ; its absolute weight will then easily be ascertained with some fair degree of accuracy. The problem is then to find "What weight must the earth be that its attraction at the distance of its centre shall be such that the relative attractions of the mountain and it may bear the proportion to each other that the deviation of the plumb-line indicates ?" In the case of Schiehallion it was found that the average weight of the whole earth must be, bulk for bulk, nearly twice that of the rocks of which this mountain is composed. The specific gravity of these were found to average about 2·5. Hence the density of the earth must be nearly 5·, or, as given by Maskelyne from these observations, 4·713.

(2) *By calculating the effects of the "increased" and "diminished" distance from the earth's centre on the vibration of pendulums vibrating above and below the surface.*

Thus a pendulum that makes 86,535 vibrations in a mean solar day in London will make only 86,400 at the equator in the same time, because the *attraction* in the latter position is less than that at the former—the attraction varying according to the Law of Terrestrial Gravity (16).

(*a*) A pendulum that beats seconds exactly at the sea level, if carried to the top of a mountain, will beat differently. In this position the velocity of its vibration depends upon the ordinary attraction of the earth at the sea level, diminished by the increased distance from the centre and the attraction of the mountain itself. The effect of the first on the pendulum may be calculated from the law of gravity, and the sum of the effects of both observed, the difference evidently gives the effect of the mountain's attraction. The size and weight of the mountain must be determined, and the attractive force of the earth compared with that of the mountain as before. In this manner the density is found to be about five times that of water.

(*b*) Comparing the vibrations of a pendulum at the top and bottom of a deep mine respectively, also furnishes data for solving this problem. Newton has shown that the effect of gravitation at any *depth* is exactly the same as if a shell of the *same depth* had been taken off the globe. Also, *if the density of the material was uniform throughout*, the attraction at the top and the bottom would vary as the radius of the earth is to the radius minus the depth.

In performing an experiment of this description at the Harton Colliery, the Astronomer Royal found a pendulum beating seconds at the top gained 2¼ seconds per day on a similar one at the bottom of a pit 1,200 feet deep. Hence the force of gravity was *more* *intense* at the lower station than at the upper by $\frac{1}{19190}$th part of the whole force—proving that the density of the interior of the earth is greater than that of the outer shell whose thickness equals the depth of the mine. After the density of this outer shell was fully estimated the density of the earth was compared with it, and calculated to be 6·623 times that of water.

(3) *By comparing the attraction of large balls, whose weight and density are known, upon a freely suspended bar, with the attraction of the earth upon the ball.*

The above mode of investigation was suggested by Henry Cavendish. He observed and calculated the attraction exercised by large balls of lead on small balls of lighter material. The simplest form consists of a horizontal rod suspended by a fine wire from a fixed support. When the rod is turned round in a horizontal plane, the wire is twisted, and, being elastic, tends to untwist itself. Now, the strength of the force which turns the rod is proportionate to the angle moved through. If two small metal spheres are attached to the ends of the rod and two larger spheres are brought near them, some indication may be obtained of the pull .they exert on the lesser balls in virtue of the effect of gravity, or the earth's attraction. Thus, when the whole is shielded from all air currents, it is found that the large balls have a measurable influence on the swing of the lesser balls when vibrating. From this may be determined what portion of the weight (*i.e.*, attraction of the earth) of either of the lesser balls is equal to the pull which the larger force exerts upon it. The mass of the larger ball being known, the density of the earth may be calculated from the other obtained data. When leaden balls are used it is found that the average density is about one-half that of lead, or, more precisely, 5·67 times that of water.

This may be taken as very near the truth. By chemical balance experiments J. H. Poynting (1878) obtained 5·69 as the mean density.

The weight of the earth is only now a matter of arithmetic, and from the data now obtained it is not a difficult matter to show that it is 5,852 trillion (5,852,000,000,000,000,000,000) tons, reckoning the volume of the earth at 259,000 million cubic miles and density 5½ times that of water

MAP PROJECTIONS.

There are several methods of projections of maps of the earth, the chief of which are the *stereographic, globular, orthographic, conical, cylindrical or Mercator's.* It is evident that the surface of the earth can be best represented by means of the artificial globe; but, owing to the vast difference in the diameters even of the largest that can be made, the minute features cannot be detailed, so that we must have recourse to maps, or plane representations of a sphere or any part of it, exhibiting the countries, seas, rivers, mountains, cities, towns, and their positions, &c. In the stereographic, globular, and orthographic the plane of projection—that is the flat surface on which the map is drawn—is supposed to pass through the centre of the earth.

The *Stereographic Projection* is generally adopted for maps of the hemispheres, the eye of the observer being presumed to be at the surface of the globe, exactly opposite its centre. In this projection a disadvantage occurs, the maps not being correctly drawn, as every part from the outline to the centre is gradually contracted. The following is an example of the method in which maps of this description are projected or drawn. The student should draw the figure for himself as described.

161. Projection of a Map of the Earth on the Plane of a Meridian.—First, draw the circles of latitude thus: Describe a circle, A B C D, of any magnitude, representing one hemisphere, or half the surface of the earth. Draw the diameters A C and B D, intersecting each other at right angles. Then A C degrees are drawn, the radii being E *a*, F *a*, H *a*, &c.; *a* being the point at which the lines drawn from D cut the polar diameter. In a similar manner draw the parallels for every 10° or degree if required. To obtain those for the Northern Hemisphere the simplest way is to turn the north part of the map to the place of the south, and proceed as before. (2) To draw the circles of longitude, divide the quadrant A D into nine equal parts, 10, 20, 30, &c., and the quadrant C D into two equal parts of 45° each, and let fall a perpendicular line from these points to the polar diameter A C at *t*. Set off on this diameter produced C *x*, equal to *s t*; then lines drawn from *x* to 10, 20, 30, &c., in the quadrant A D, will divide the radius D O in the points 1, 2, 3, 4, 5, 6, 7, 8, through which the radii of longitude are to be drawn. It is now requisite to find the *centre* through which these circles may be drawn. This may be done as follows: To find the radius of the circle of longitude A 3 D, join the points A 3 and D 3; divide these two lines each into two equal parts in *s*, and let fall the perpendicular lines, and the point of intersection is the centre of the circle. The other centres may be found in a similar manner.

In the *orthographic* projections all the parallels are in planes perpendicular to the plane of projection, being represented on the map by straight lines, all the meridians except the one in the centre appearing as elliptical curves. This method has the disadvantage of contracting the outer parts or margins of the map. Hence it is not generally used, though modifications of it are used for the maps of Africa and South America.

As the three projections above described are only adapted to the construction of maps of the world, some other method had to be devised for drawing maps of individual countries or continents. This method is termed—

The Conical.—In this projection all the parallels of latitude are arcs of circles drawn from a common centre—namely the apex of the cone—the meridians being straight lines projected from the same point. This projection is well suited for maps of countries, as Europe, Asia, North America, &c. Thus, for example, in drawing the map of Europe it is found that the common centre of all the parallels of latitude is at 6·7° beyond the pole. Draw a line for the central meridian of the map, and assume any distance from 10°; set off six times and the sixth extreme will be the pole, and 6·7 degrees more laid down beyond it will be the common centre of all the parallels, which may at once be drawn. To draw the meridians take the number of miles in a degree of 30° latitude, namely, 51 96 miles; set this off on each side of the central meridian on the *parallel or circle of* 30° *of latitude.* From these points of division draw right lines to the common centre or apex of the cone, and they will represent the meridians.

Mercator's or Cylindrical Projection.—This projection was devised by Gerard Kauffman, to facilitate the laying down of courses on the sea, enabling the mariner, while steering by his compass, to work with *straight lines* only, the meridians and latitude circles being represented in parallel straight lines. This projection is drawn on the circumscribing cylinder of a sphere (the area of a sphere is equal to the convex area of the cylinder circumscribing it), the eye being supposed to be the centre of the sphere. A map of this projection is constructed thus: A line of any length is drawn to represent the equator. This is divided into 36 or 18 equal parts for meridians, at 10° or 20° apart, and the meridians are then drawn through these perpendicular to the equator. From a table of meridianal parts (a table of the number of minutes of a degree of longitude at the equator comprised between that and every parallel of latitude up to 89°) take the distances of the parallels and of the tropics and arctic circles from the equator, and mark them off above and below it; then join these points, and the projection is complete. There is one disadvantage of this method, namely, the gradual enlargement of the parallels as they recede from the equator, causing all countries in the high latitudes to be greatly distorted. Hence these maps do not usually extend beyond latitude 75°; but this circumstance does not usually detract much from their great value and usefulness to the mariner, and even to the student of physiography.

MOTIONS OF THE EARTH.

162. Diurnal Motion.—Real and apparent motions are not at first readily distinguished from each other. For many years it was supposed that the *apparent* motion of the sun was real. That the heavenly bodies really move, and by so doing cause the apparent, diurnal motion, we can have no experience. Neither can we readily perceive the motion of our earth. But by examining the reasons for each, we see which is most probable, that of the earth round its axis, or of all the celestial bodies around the earth in the space of 23 hours 56 minutes. Either the celestial bodies revolve in the space of 23 hours 56 minutes in great or small parallel circles, according to their apparent distance from the celestial poles, or the cause of that apparent diurnal motion is a real motion of the earth about an axis in a direction from west to east.

This latter supposition will explain the diurnal phenomena. Thus by the rotation of the earth about an axis, the horizon of each spectator has a motion and will revolve in the celestial sphere instead of the sphere with its circles, thereby causing the parts of the celestial sphere to be successively uncovered and become visible, the same as they would do by a motion of the imaginary sphere itself carrying the bodies situate in it.

The vast distances and magnitudes of the sun and planets may be brought against the diurnal motion of these celestial bodies. Thus the sun, above a million times larger than the earth, would have to travel at the rate of about 600 million miles in twenty-four hours, which is contrary to that rule of philosophy by which effects are deducted from the simplest cause.

Again, it has been stated in the earlier pages of this book, that every portion of matter is attracted by every other portion, and that the force of the attraction depends upon the *quantity of matter and the distance* (see 15). Hence it is contrary to the laws of gravity that a large body should revolve round a smaller. When a body moves in the circumference of a circle, we know there is requisite a force tending to the centre to keep it continually in that circle. Now, we can assign no force acting upon the sun and planets to make them describe the diurnal circles.

Another argument brought forward to prove the earth's rotation, is the shape of the earth, which we know is a sphere flattened at its poles. Thus its present form is said to be exactly that which a fluid mass, as the earth is supposed to have been at one time, would have assumed supposing it were made to rotate rapidly.

Sir John Herschel even asserts that if the earth had always the solid form it has now, yet its daily motion would have caused just such a shape as it has now.

We may therefore conclude that the diurnal motions of the celestial bodies are only apparent, and that these appearances are produced by the motion of the earth about an axis parallel to the apparent celestial axis.

163. Annual Motion.—The sun appears in the course of a year describe, on the concave surface of the heavens, a great circle called the *ecliptic.* This apparent annual motion of the sun is explained by supposing that either the sun moves round the earth or the earth round the sun in an orbit nearly circular. That it is the earth moving round the sun, and not the sun round the earth, is also satisfactorily proved from the knowledge of the principle of gravity. The sun, earth, and planets mutually attract each other in proportion to their quantities of matter. Then from the laws of motion—which are

1st. A body if at rest will remain at rest, or if in motion will move in a straight line with uniform velocity, unless it is acted on by some extraneous force.

2nd. The effects produced by a force acting upon any body is the same, both in direction and amount, whether the body is at rest or in motion.

3rd. When a force acts on a body, the total quantity of motion communicated is proportional to the force so acting.

It follows that they must come together, or each of them revolve in an orbit round a fixed point, the common centre of gravity of all the bodies.

The *mass* of the sun, as well as its *magnitude*, is vastly greater than all the planets together, so much greater that the common centre of gravity lies within the body of the sun. The sun itself, in fact, will move about this point, but in a path very small compared with the orbits of the planets. The planets revolve revolving about the sun, they revolving about a point near his centre.

We thus see that the earth has two independent motions ; firstly, its annual motion in an elliptical orbit, often called the plane of the elliptic, the plane of which passes through the sun ; and secondly, its rotatory motion about an axis, which is termed its diurnal motion.

Respecting the **apparent motion of the sun,** if we compare it with that of the stars we find some points of difference. The stars, when they reach the meridian, have always the same declination, not so the sun. The sun has an apparent motion to the east in opposition to that of the diurnal revolution of the stars, amounting to nearly 1°. Thus, when the earth has made one revolution upon its axis, the sun, instead of being on the meridian, is a degree to the east. The earth performs its revolution in 23 hours 56 minutes, but it is 4 minutes longer, or 24 hours from the time the sun leaves the meridian till it re-appears on the meridian the next day. This is called the solar day; and the time taken by the earth and stars to complete the revolution is termed the sidereal day.

Another fact we may mention is that the sun's apparent eastward motion is not the same each day. Hence the solar day, at different times of the year, is not of equal length. The reason of which is—

1st. Its real movement depends upon the earth's motion in her orbit, and which varies, being sometimes quicker and sometimes slower.

2nd. It is performed on the ecliptic, and not on the equator, to which it is considerably inclined—nearly at an angle of 23½°.

Hence the necessity for using a *mean* solar day, being the average for the year. The difference between the apparent and *mean* solar days never exceeds fifty-one seconds, but this, accumulating day after day, makes at times a great difference between the *mean* and apparent noon, amounting sometimes to as much as sixteen minutes. This difference is called the EQUATION of TIME.

On four days of the year the mean and apparent time agree. These are April 15, June 14, August 31, and December 24—on these days there is no equation of time.

The *plane of the ecliptic* along which the sun appears to move is inclined to the celestial equator at an angle of 23½°. The time which elapses from the moment of the sun leaving a particular star till its return to the same star again is called a *sidereal* year, being equal to 365 dys. 6 hrs. 9 min. 9·35 secs. solar time, or 366 dys. 6 hrs. 9 min. 9·35 secs. sidereal time. But the most important measure of the length of the year is that which depends on the time which elapses between the sun's departure from and arrival at the equinox. This is 365 dys. 5 hrs. 48 min. 46·15 secs. of mean solar time, and is called the tropical year. During this time the earth in its orbit travels about 574 millions miles, being at the rate of about 65,533 miles an hour, or nearly 19 miles per second.

164. Day and Night.—During the earth's rotation on its axis only one-half of its surface can be exposed to the sun's rays at any one time, this being lighted while the other half is in darkness.

But the length of day and night varies according to the *seasons*, the chief causes of which are, *first*, that the orbit of the earth's revolution round the sun is not a perfect circle, but an ellipse ; *secondly*, that the earth's axis in performing this revolution is not perpendicular, but inclined to an angle of 66° 32′ to the plane of its orbit, or 23½° (23° 28′) to the equator. The diagram accompanying will assist in explaining the effects of this elliptical orbit and the inclination of its axis.

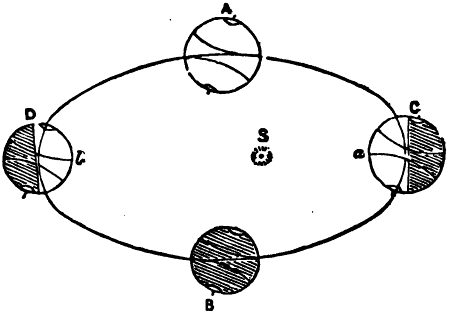

Fig. 6.

165. Seasons.—The earth is represented at four different positions in its yearly orbit, S being the sun, A representing the position at the vernal equinox. The whole hemisphere from pole to pole is illuminated by the sun, so that during the rotation every part of the earth will have an equal share of light and darkness, day and night being equal. Similar at B. At any other position day and night are respectively shortened and lengthened. When at D, the summer solstice for the northern hemisphere, the south pole will be in darkness, and within a circle of 23½° at the north pole the sun will not set. When at C it will be just the reverse. When the part presented to the sun is at *a*—namely, on the 22nd of December—it is midsummer to all the southern parts of the earth and winter to all the north, and as it gradually proceeds on its journey towards *b* the northern regions gradually receive more and more heat and longer and longer days, till their midsummer comes on the 21st of June, being just the reverse with the southern regions.

166. Nutation.—If the axis of the earth were perpendicular, instead of being inclined, the length of the day would be always and everywhere the same, and we should have no change in the seasons. Hence, if the angle of inclination should change it is evident it would cause a change in them; and this does actually take place. The angle at present is 23° 28′, but it gradually decreases—namely, at the rate of about 48″ in a century—diminishing for an immense period, after which it will begin to increase again—that is, the axis itself revolves in a small ellipse, but does not always point exactly to the same place in the heavens, *thereby causing the variation in the obliquity of the ecliptic.* This motion is termed nutation,[*] the cause of which is the influence of the planets upon the earth. The circle described is about 2° 42′ in diameter, its revolution occupying a period of about 270,000 years.

167. Precessional Motion.—Besides the above there are other movements, the chief of which is that called the *precession of the equinoxes*—that is, they *precede* their time. This movement is caused by the attraction of the sun and moon on the equatorial regions—namely, on the portions of the earth which the centrifugal force have caused to bulge out, the effect of which is that the *equinoctial*[†] *points* move westward (recede) 50·224″ per annum, causing the equinox to occur nearly 20 minutes earlier than it otherwise would. Hence, in the course of ages summer will be where winter is now. This movement, *uninfluenced by any other motion,* would cause the equinoctial points to perform the circle of the equator in a period of 25,868 years—that is, *the seasons will coincide with each part of the orbit once in that period.* But this movement is influenced by another motion, the result of which is that this cycle of changes is shortened. The latter motion is termed the *revolution of the apsides*,[‡] caused by the attraction of the planets. The *apsides* are the points at which the earth is nearest and farthest from the sun. The line connecting these points is called the *line of the apsides.* This line does not keep continually directed towards the same point in the heavens, but slowly revolves, and the result of the combination of this revolution with the precession causes one cycle of the seasons to be performed in about 21,000 years, or 4,568 years sooner than it otherwise would.

168. Eccentricity of Earth's Orbit.—This orbit is an ellipse with the sun occupying one of the foci, thus agreeing with Kepler's laws. In winter the earth is much nearer the sun, being three million miles nearer than in summer. This is termed the *eccentricity of the orbit*, an amount which is not, however, constant. It is yearly growing less, and will do so for about 23,900 years, when the amount of the eccentricity will be only about half a million miles, and the earth's orbit nearly a perfect circle. It will then gradually increase again until it reaches its maximum, or a difference of more than twelve million miles between the position of the earth in summer and in winter. That is more than 8½ million miles farther from the sun during winter than it is at present.

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[*] Nodding.

[†] The points where the ecliptic crosses the equator.

[‡] A curve.

If winter then occurred in the Northern Hemisphere while that portion of the globe was turned away from the sun, the winters would be 36 days longer than the summers, instead of 8 days shorter as now. Thus the winter would be 201 days and summer 164. The result of this would be an accumulation of snow in the Northern Hemisphere too vast for the summer's heat entirely to melt, so that winter after winter, for many years, the snow would go on accumulating. A lower temperature would naturally result, thereby bringing about a cold period in this part of the globe.

Now, it has been suggested by some of our most able geologists that in this way we had the *glacial* period. Thus, some 210,000 years ago, the eccentricity was nearly at its greatest, being about 10½ million miles, and owing to the precession of equinoxes, the equinoxes and solstices do not take place on two successive years in exactly the same part of the earth's orbit, performing a complete cycle in about 26,000 years, it happened that *the earth was in perihelion during the northern summer*. This, as above stated, would cause the winters to be much longer, and cold more intense, and the summers to be hot but too short to melt the snow and ice formed during the winter months No doubt it is principally to the variations in the eccentricity of the earth's orbit, we owe the various changes in the climate which the rocks of our globe reveal. This is the cause probably, though climates may have been modified by the distribution of land and sea, which has ever been on the move.

LATITUDE AND LONGITUDE.

169. Definitions.—If we know the *latitude and longitude* of any place we know its exact position, but if only one of the two is known its position is undeterminable, as thousands of places have the same latitude, or the same longitude, but not both. So we see both are necessary. In latitude all nations measure from the equator, but longitude is measured from many places. Thus, we reckon from Greenwich; therefore one half of the world will be east, and the other half west. Hence the longitude of any place cannot exceed 180°, namely half of 360°, the circumference of a circle. Now comes the question : *How can the latitude and longitude be found?* We will try to make this plain, but first the student must understand the terms used, short definitions of which we here give :—

The position of a heavenly body is generally referred to two great circles drawn on the celestial concave, namely, the *celestial equator* and the *ecliptic*. The *celestial pole* is the point in the heavens which the axis of the earth would reach, prolonged, and round which the stars appear to move. The *celestial equator* is a circle described on the heavens by the plane of the earth's equator produced; the *zenith* is the point of the heavens exactly over the observer's head, and *nadir* the point in the celestial concave exactly opposite his feet. The *horizon* is of three descriptions, namely, *sensible*, *rational*, and *visible* or *apparent*. The *sensible* horizon is shown by a plane touching the earth at the spectator's feet, and there extended to the celestial concave. The *rational* horizon is shown by a plane through the centre of the earth drawn parallel to the visible horizon and cutting the sky. The *visible* horizon is where the *sky and earth appear to meet*, forming a circle round the spectator, of which he is the centre. The *altitude* of a heavenly body is the angular distance of that body from the horizon, measured on a vertical circle.

170. The **Latitude** of an observer may be found by the altitude of any celestial object when on the meridian*. Thus, the sextant† being placed in a vertical position, the upper or lower limb of the sun, by moving the index, is brought down to the horizon. Seen directly, this index shows the altitude. The sun is known to be on the meridian when it ceases to rise higher, or when the index angle ceases to increase. The latitude is always equal to the sum or difference of the zenith distance and declination—the zenith distance being always 90° altitude, and the *declination*, or the position of the sun and principal stars from the celestial equator, is given in the "Nautical Almanack." Hence the latitude is easily known.

RULES WHEN TO ADD AND WHEN TO SUBTRACT.—*If the zenith distance and declination are both north or both south add for the latitude; but if one be north and the other south their difference is the latitude. When both are north or south then the latitude is north or south; if one is north and the other south the latitude is of the same name as the greater.*

Another method of obtaining the latitude is to measure the altitude of the *pole star*. Thus, if we were at the equator the north or pole star would appear on the horizon, its altitude being 0°; but supposing we travel northwards for 206 miles we should find its altitude 3°, which is the latitude. In like manner, if at a certain place it appeared 40° above the horizon, then the latitude of that place is 40°. This is supposing the pole star continually due north, which is not quite correct, it being always about 1½° from the pole. Hence correction should be made for this.

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* Every place is supposed to have a meridian passing through it, and when the sun comes to that meridian it is noon, or midday, at that place.

† *Sextant*, so called on account of consisting principally of a sixth part of a circle or an arc of 60°.

Other methods are—(1) By observing the altitude of a star when on the meridian, and calculating the latitude from its own distance from the polar star. (2) By taking half the sum of the greatest and least altitudes of a circumpolar star.

171. **Longitude.**—The earth makes one revolution on its axis every 24 hours. Hence if the sun or star is on the meridian at any place it will be on the meridian of another place (360° ÷ 24) 15° west of the first in one hour. It is on this fact that all methods of calculating the longitude are based. The difference in time at two places at the same moment gives the number of degrees of longitude they are apart, every four minutes' difference corresponding to 1°. To find the time of day, termed *local*, at the place of observation, all that is necessary is to observe the moment when the sun crosses the meridian, it then being 12 o'clock; and then, glancing at a watch or chronometer that is carefully set to Greenwich time,* the difference between the two gives the longitude. Thus, if the watch shows half-past one then the place is 15° × 1½ = 22½° W. Had the Greenwich time been earlier than that of the place, say 11 o'clock, then the longitude would have been 15° × 1 = 15° E. of Greenwich. Other methods are—(1) In the "Nautical Almanack" the Greenwich time at which the moon is at certain distances from certain stars is given. Mariners note the local time (as above) at which the moon is at the same distances from these stars, and so the longitude is known. (2) The eclipses of Jupiter's satellites are seen by all observers in all parts of the globe at the same instant. These exact times of occurring are given in the "Nautical Almanack" a long time beforehand—namely, Greenwich time. Hence the difference between the *local* time of occurrence and the given Greenwich time is the longitude in time. Thus, suppose the eclipse is to take place at 2h. 15m. p.m., Greenwich time, and at the observed place it takes place at 4h. 55m. p.m., then the difference, namely, 2h. 40m. = the longitude in time = 160m., but 4m. = 1° ∴ longitude = 160 ÷ 4 = 40° east of Greenwich. Observations of lunar transits, and the occultations of fixed stars, afford the means of determining longitude.

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* Many ways have been tried so that the correct Greenwich time may be known, as no watch or clock can keep apparent time. When telegraph wires are laid from one place to another the time of either place may be easily known at the other. On sea chronometers are used, which answer for a short time; but methods have to be resorted to to check them, as they are liable to variation.

DISTANCES OF HEAVENLY BODIES, OR PARALLAX.

173. How to find the Distance of the Heavenly Bodies. It is from the *parallax*, or the apparent change of position in an object arising from a real change of position of the observer, that the distances and magnitudes of planets are calculated. These are measured by the angle formed at the object by two straight lines drawn from it to the two positions of the observer, but as the distance of any planet from the earth is extremely great we may assume without any sensible error that lines drawn from any one of them to the earth's centre, and any point on its surface, are absolutely coincident when the body is in the horizon. The angle made by these two lines is called the *horizontal parallax*.

In taking the horizontal parallax the two stations of the observers should be as far apart as regards latitude as possible, and also be situated nearly on the same meridian. Having these properties are the stations at Greenwich, N. lat. 51° 28′ 38″, and the Cape of Good Hope, S. lat. 33° 56′, E. long. 1h. 13m. 55s. To find the distance of the moon, take this as the base line of a triangle, and from the angle made by lines drawn from the moon to these places, the sides of the triangle can be determined, in proportion to the earth's radius. The parallax is greatest when the object to be measured is on the horizon. The mean parallax of the moon is 57′ 2·5″, which corresponds to an average distance of 60¼ times the earth's radius, or 238,851 miles. Thus, when the parallax is obtained we have the three angles of a right-angled triangle, and one side to find the other sides. By trigonometry let A represent the parallax, and a the given side, or radius of the earth, C the right angle, and B the remaining angle; then $B = 90° - A$, and calling the remaining sides b and c respectively, c being the hypothenuse, and proceeding from the centre of the earth. Now, $\frac{b}{a} = \tan. B$, or $\log. b = \log. \tan. B - 10 + \log. a$; and $\frac{a}{c} = \sin. A$, or $\log. a - \log. c = \log. \sin. A - 10$; or $\log. c = 10 + \log. a - \log. \sin. A$. Hence, substituting data, $A = 57' \, 2{\cdot}5''$; $a =$ earth's equatorial radius $= 1$; $\log. c = 10 + \log. 1 = \log. \sin. 57' \, 2{\cdot}5'' = 10 - 8{\cdot}2204661 = \log. 1{\cdot}7795339 = \log.$ of $60{\cdot}249 =$ number of times earth's equatorial radius (say 60¼), which gives the distance as $3962{\cdot}8 \times 60{\cdot}25 = 238{,}858$ miles.

Generally, in the case of planets, the parallax is too small to be measured directly, so that other circumstances have to be taken advantage of. Thus the transit of Venus over the sun's disc on December 9th, 1874, was taken advantage of, with the view of obtaining the correct parallax of the sun, which is now given as 8·879″,* giving a little over 92 million of miles as the distance of the sun from the earth.

174. Sun's Distance.—More than 2,000 years ago it was suggested that it would be possible from the distance of the moon to determine the distance of the sun. The method consisted in measuring the angular distance between the centres of the sun and moon when the latter is *dichotomized*, that is, when exactly one half of its surface is illuminated. When this takes place, the lines joining the earth and moon must form, with that joining the moon and sun, an exact right angle, as in Fig. 7. The distance of the moon being known, and the angle between the sun and moon as seen from the earth measured, we have all that is necessary to solve the right angled triangle MSE—and hence the sun's distance E S. This method did not prove successful, owing to the surface of the moon being rough, so that it is impossible to tell exactly when its half is illuminated.

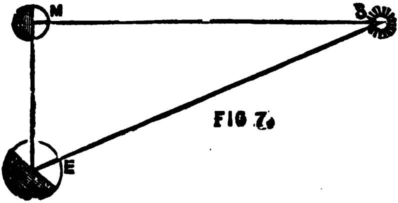

FIG 7.

The next method was that suggested by Kepler, namely, to take the distance of Mars when it comes nearest the earth, by the method of parallax, as in the case of the moon. Thus, suppose an observer at Greenwich looking at Mars, and another at Cape Town. He would not in that case measure the angle of Mars from the polar axis of the heavens, but merely measure the distance of Mars from some small star near it. The observer at the Cape would also measure the distance of Mars from the same star; the difference between these measured distances would show the small apparent shift of position of Mars, due to its being viewed from two different stations. We thus obtain the parallax of Mars, and thus its distance, and employing Kepler's law, we obtain a knowledge of the sun's parallax. Thus, in 1862 the result 8″·94 was arrived at, giving a distance of 91,430,230 miles.

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* When we know the angle the earth's disc subtends from a planet its distance can approximately be found by dividing 206,265 (the seconds in arc equatorial radius) by the number of seconds in the angle. Thus in the case of the sun the angle = 8·879 × 2 = 17·758″, therefore distance roughly = $\frac{206265}{17{\cdot}758}$ = 11609 diameter of the earth = 7925·6 × 11609 = 92,008,290 miles.

In June, 1879, Mr. Gill deduced from his heliometer observations of Mars, at Ascension, that the resulting parallax is 8″·78. Maxwell Hall obtained an almost identical value from his observations at Jamaica during the same opposition of Mars, and Mr. Downing, of the Greenwich observatory, from a comparison of the Melbourne and Greenwich observations of Mars and comparison stars, deduces the value of 8″·96.

175. Transit of Venus.—Another method is the making use of the transit of Venus. Thus, by noticing the position of the black spot traversing the face of the sun, from stations on the north and south side of the earth (extremities of the diameter), we see the shift of its position on the sun, and so can measure a certain distance upon the sun in miles, and can say that a certain part of the sun's diameter measures so many miles. Thus we get the whole diameter. This we have only to multiply by certain known proportions and we get the sun's distance.

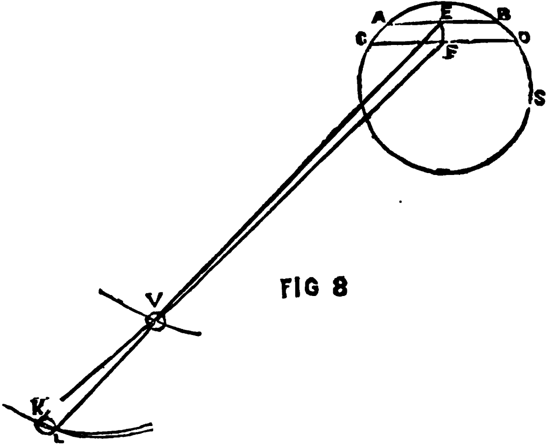

FIG 8

To make this plainer, let K and L in Fig. 8 be the two stations on the earth where the observations are made, being supposed, for the sake of simplicity, to be at opposite extremities of the earth's diameter ; V the planet Venus, and ABCD the sun. When Venus is viewed from K it will seem to travel along CD. When viewed from L its path will be along AB. The observer at K notes the exact time it takes to traverse CD, and the observer at L the time it takes to traverse AB. From a comparison of these times with the rate at which the planet is travelling, the exact part of the sun's disc, where the lines pass over, may be known; hence the perpendicular distance EF between them. If, at the time of transit, the distance between Venus and the earth and between Venus and the sun were the same, the space between the two paths of transit would be equal to the distance between the two stations at which the observations were made—that is, EF would equal KL, but the distance of the earth from the sun is to the distance of Venus from the sun as 10 : 7·2 = 100 : 72. Hence distance of the earth from Venus is to the distance of Venus from the sun as 28 : 72. Therefore EF = $\frac{72}{28}$KL, so that if the distance between the two stations KL = say 7,000 miles, then EF = 18,000, and supposing EF had been found = $\frac{1}{x}$ of the whole diameter of the sun, then its length would be 18,000x, and therefore known.

The sun's diameter in angular measure is 31′ of arc. The radius is 107 times the 31′ ∴ sun's distance = 107 × sun's diameter. Dr. Lisle suggested another method. He proposed to record at two stations either the instant of ingress, or beginning of the transit, or the instant of egress, or ending. Thus an observer at the extreme east of the earth would see the ingress earlier than an observer at the extreme west. During this time Venus will have passed over a certain part of her orbit. If the stations are 6,000 miles apart, Venus will have travelled over 4,300. The proportion of this time to the period of Venus, gives the circumference of the orbit of Venus in miles, whence the earth's distance from the sun is easily obtained.

In 1882 the mean solar parallax, deduced from the observations of the transit of Venus made by the Belgium observers, was 8·911″, giving a distance of 91,762,000 miles, which may be considered very near to the true distance. Other methods depending upon the velocity of light have been tried, and results very similar obtained. Thus Jupiter we know has four moons. These go round their primary, and to us sometimes appear to go across, and sometimes to go behind, and sometimes to be eclipsed by his shadow. The times of these disappearances have been calculated, and it was found that at different periods of the year the observed times differed from their calculated times. These transits were delayed sometimes to the extent of 16 seconds—this delay being due to the length of time it took for light to traverse the diameter of the earth's orbit. Now, it has been found, quite independently of the sun's distance, that light travels at the rate of 185,300 miles per second. Hence 16 × 60 times this gives the diameter of the earth's orbit, or more correctly $(16\frac{35}{60} \times 60)$ 185,300 = 184,571,500 miles ∴ the radius, or sun's distance = 92,285,750 miles.

176. The **Parallax** of the **Chief Planets** is as follows: Mercury 16″, Venus 32″, Mars 24″, Ceres 5″, Jupiter 2″, Saturn 1″, Moon 57′ 2·7″, &c. The diameter of these planets may be measured by means of micrometers, and found to be as follows: The Sun 1923·7″, Mercury 11″, Venus 57″, Mars 26·8″, Jupiter 41″, Saturn 18″, Moon 1920″. So that we can compare the real diameters of these bodies with the diameter of the earth. For diameter of planet : diameter of the earth :: angle planet subtends at the earth : angle earth subtends from planet. Thus, taking the sun, for instance, we have the proportion $x : 1 :: 1923·6 : (8·879 \times 2)$; or, diameter of the sun = 1923·6′ ÷ 17·758 = 108 times the diameter of the earth = 855,964 miles, nearly.* In a similar manner we find the diameter of the other planets to be—Mercury 2,961 miles, Venus 7,511, Mars 4,921, Jupiter 88,390, Saturn 71,904, Moon 2,159.†

THE MOON—ECLIPSES AND TIDES.

177. The Moon.—This satellite revolves round the earth in an elliptical orbit, the earth being one of the foci, and carried with it round the sun. The orbit is only an ellipse with reference to the earth, being, in fact, a curved line, always more or less concave to the sun, when regarded as a movement in space. These two motions may be entirely separated, so that we may regard its orbit round the earth strictly as an ellipse, the eccentricity of which is rather greater than the earth's $(\frac{1}{18}\cdot\frac{1}{112})$; the mean distance from the earth being 238,851 miles, the point where it is nearest the earth, called the *perigee*, being about 226,000 miles distant, and the *apogee*, or farthest point, 252,000 miles. At perigee its diameter measures 33′ 31″, and at apogee only 29′ 21″. This great difference is owing to the variation of distance. Its mean apparent diameter is therefore about 31′·2, rather smaller than that of the sun. Hence its real diameter is about 2,160 miles,‡ or a little more than one-fourth that of the earth's. Her surface is about 14,600,000 square miles. Though the volume of the earth exceeds that of the moon's about $49\frac{1}{2}$ times, her mass exceeds that of the moon's nearly $81\frac{1}{2}$

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* The diameter of the sun given in the table is obtained by taking the parallax as 8·943″ instead of 8·879″, as used here.

† The contents in cubic miles = cube of the diameter multiplied by ·5236, and their mass, compared to the earth's, equals the cubic contents multiplied by the specific gravity.

‡ Diameter of planet : diameter of earth :: angle planet subtends at the earth : parallax, or angle earth subtends from planet, or, $x : 7914 :: 31′·2 : 57′ 2·5″ \times 2$.

times. Hence the moon's specific gravity is only about three-fifths that of the earth's (·61), or about 3½ times that of water.

The moon in her course round the heavens follows a track which lies in a zone about 10⅓° wide, the central line of which is the sun's track. This circuit she completes in 27 days 7 hours 43·6 minutes, or a *sidereal* month: but to complete a lunar month she has to round the heavens from the sun to the sun again, the sun slowly advancing all the time. This takes nearly a twelfth of a sidereal month more, as the sun takes one year to go once round the heavens, hence in one month he would go about one-twelfth. This the moon has to overtake, so that it really takes 29 days 12 hours 44 minutes 2·87 seconds to entirely complete its circuit, returning to the same position with regard to the earth and sun. This period is called a *lunar* month, or *lunation*. It is also sometimes called the *synodical* month.

The time of the moon's rotation on its axis is exactly the same as its revolution round the earth, and in consequence of this fact the moon always turns the same side to the earth. Strictly speaking, a little more than half of the moon's surface presents itself to view, about $\frac{29}{50}$ of the whole. This is owing to the motions not being *both* uniform, and the axis of rotation not being perpendicular to the plane in which she travels. In her motion of revolution she at one time gains, and at another loses, on her motion of rotation, the effect of which is that at one time she appears as if rotated a little backwards and at another is rotated a little forwards from her mean position; so that two edges of her surface, one on the east and one on the west of her medium face, are brought to view. This is termed *libration in longitude.* Again, her axis is inclined 1° 32′ from the perpendicular; hence we sometimes see a portion of her surface beyond the northern pole, and a narrow northern fringe beyond her medium face, and at other times a narrow southern fringe. This is called the *libration in latitude.*

178. The Phases of the Moon prove it to be a spherical body illumined by the sun. When in conjunction with that luminary the moon is invisible. When moving from the sun towards the east it is first visible, it being now called the *new moon*, and appears as a crescent; when 90 degrees from the sun—namely, at a right angle—there appears a half-moon; as it recedes farther it is gibbous; when in opposition it shines with a full face, being then called full moon. On its journey towards the east, approaching the sun, the appearances are just the reverse, first being gibbous, then halved, and lastly a crescent; after which it disappears from the superior brightness of the sun and the smallness of the illuminated part turned towards the north.

The whole moon may also be observed a few days before and after the new moon. This is owing to the reflection of light from the earth. When the moon becomes considerably elongated from the sun it is then out of the way of this reflection.

The rising and setting of the moon is most interesting at and near full moon. At full moon it is in or near that part of the ecliptic opposite the sun. Hence, at full moon, at midsummer, it is in or near the most southern part of the ecliptic, and consequently appears but for a short time above the horizon; thus there is only little moonlight in summer, when it would be useless.

In mid-winter, at full, it is within or near the northernmost part of the ecliptic, hence it remains long above the horizon, thereby causing the moon-light to be greatest when wanted most. This is even more noticeable the nearer we get to the north pole. There, at mid-winter, the moon does not set for fifteen days together, namely, from the first to last quarter.

Again, the moon rises later every day, owing to its motion from west to east. These retardations are not equal, being least in northern latitudes, when the moon is near the First Point of Aries, or the vernal intersection of the ecliptic and the equator, and greatest when near the beginning of Libra. To this variation of the retarding of rising, according as the moon is in or near different parts of the ecliptic, we owe what is termed the *harvest moon*. At the full moon nearest the autumnal equinox the moon is observed to rise nearly at sunset for several nights together. Thus, it being near the part of the ecliptic opposite to the sun, and at the autumnal equinox the sun being at Libra, the moon must then be near Aries, when the retardation of her rising only amounts to a few minutes, and as the moon at full rises at sunset, the cause of the whole phenomenon is apparent.

179. The surface of the Moon, as seen through the telescope, is very diversified. There are spots differing very considerably in degrees of brightness. Some are almost dark; these were supposed by Kepler and others to be seas, but are now proved to be portions of the solid surface of the moon, which, as far as can be judged, seems to be an entirely solid globe. These dark regions, which are even now called seas, correspond precisely with the regions which would be oceanic if there were water in the moon. These regions are, no doubt, great plains below the ordinary levels. They are supposed to be old sea-bottoms, some older than others, which have undergone upheavals and other changes since the waters had disappeared, and some which had undergone no change apparently since that time. According to Proctor, these dark regions show unmistakable evidence of long eras of time, during which water existed on the moon. Some of the principal of these are—The seas of (1) Tranquillity, (2) Showers, (3) Crises, (4) Serenity, (5) Clouds, (6) Liquids, &c.

180. Lunar Mountains.—On or near the dark spots appear a variety of bright detached ones. These are without doubt lunar mountains, of a ring shape, or great craters, being very large compared with the moon's volume, and even absolutely larger than the largest craters on our globe. The lunar ring-shaped cavities are commonly arranged by astronomers into three classes: Walled Plains, Ring Mountains, and Craters. The Walled Plains appear to have been formed first by volcanic fires upheaving a large region, and forming all round it a ring of raised rocky matter, the interior appearing to have been filled at a later period with fluid matter carrying in and depositing substances of the same kind, as those which form the surface of the so-called seas.

The ring mountains are smaller, and the craters smaller still. The principal of these ring mountains, &c., are named after celebrated men, such as Tycho, Copernicus, Kepler, Aristarchus, Plato, Aristotle, Archimedes, Linné, &c. Of the walled plains, some are very large indeed, thus Schickard is 460 miles in circuit, and the ring in parts 10,500 feet high; Gassendi, a walled plain 55 miles across. Of the ring-shaped mountains Plato is one of the most interesting. Its enclosed plain appears very dark, hence it was formerly called Greater Black Lake. This plain is nearly circular, about 60 miles in diameter, and containing about 28,000 square miles. The ringed wall has a height varying from 3,800 feet to about 7,300 on the western side, and rising to even a greater height on the eastern side. The floor contains several small craters. It also sometimes appears darker than at other times, owing probably to the effect of contrast.

Tycho is a great circular mountain in the southern hemisphere, situated in the centre of a wonderfully irregular mountain region, over which lie hundreds of craters and ring mountains, while from Tycho itself radiations extend in all directions. These have been compared to cracks in a globe which has been burst by the expansion of matter within it, or by the contraction of the globe upon unyielding matter within. The wall rises to a height of about 16,000 feet, the enclosed space having a diameter of 50 miles, while in the centre is a mountain leading to a height of about 5,000 feet. Another crater still larger than Tycho is the one named *Copernicus*, situated about 9° north latitude. It has a diameter of 56 miles, the floor being about 11,000 below the ridge of the surrounding ring. In the centre was a mountain with six heads, two of which reach to a height of about 2,400 feet. In the region around Copernicus an interesting peculiarity of the moon's surface is the immense number of small craters to be observed there, also many minute pits. Mr. Proctor is of opinion that, at least the smaller of the craters and many of these minute pits, may have been produced by meteoric masses falling upon the moon's surface, which at a certain period must have been so heated as to be plastic to receive impressions from without, yet firm enough to retain them.

Besides these ring-shaped mountains, ranges of mountains such as the Lunar Apennines may be seen. These chain show a greater steepness on one side than on the other, the side towards the so-called seas being the steepest. This is precisely the same as on the earth. Other features noticeable on the moon's surface are valleys, ravines, gorges, clefts, or rills; also closed cracks similar to those called by geologists *faults*.

The moon appears to have, if any, only a *very thin* atmosphere, as shown by the sudden disappearing and re-appearing of the stars when she passes over them, and also by the blackness of the shadows of the lunar mountains. Neither are there any signs of water to be found there, though there are strong reasons for believing she at one time possessed both water and air.

181. Eclipses.—All our light in reality comes from the sun. Hence if, in the course of the revolutions of the planets and satellites, any two of these come into the same straight line with the sun, that luminary will be wholly or partially hidden from the body most remote from it, which will therefore be more or less incapable cf reflecting light. The most important of these various phenomena are the eclipses of the sun and moon.

The orbit of the moon is inclined to that of the earth at an angle of 5° 8′. If it were not inclined there would be an eclipse of the sun and moon once every fortnight. Eclipses of the sun take place when the moon, passing between the sun and the earth, intercepts its rays. Those of the moon take place when the earth, coming between the sun and moon, deprives the moon of its light. Hence an eclipse of the sun can only take place when the moon changes, and an eclipse of the moon only when the moon fulls, for *at the same time of an eclipse*, either of the sun or of the moon, *the sun, earth, and moon must be in the same straight line.* A *total eclipse* of the sun occurs when the moon is near the earth, and in the same straight line as the earth and the sun. An *annular* eclipse takes place when the moon is more remote from the earth, but in the same straight line. It often happens that the moon in her orbitual motion passes before and hides from a spectator on the earth some of the fixed stars and occasionally one or other of the planets. These occurrences are called *occultations*.

182. The Tides are occasioned chiefly by the attraction of the moon upon the earth, but assisted partly by the sun. Considering the earth as a solid, rigid body, the moon's attraction acts upon its centre; but the waters of the ocean directly below the moon experience and obey a greater attraction owing to being nearer, thereby causing an immense flat wave to be heaped up below the moon. But, at the same time, the centre of the earth is attracted more than the waters on the other side of the earth, causing a similar wave to be heaped up there also; hence it is evident that it is the *difference* of the moon's attraction upon the waters on opposite sides of the globe, vertically below her, that causes the two tides.

To make it plainer, let M in the annexed figure represent the moon, and E the earth—then the waters at A, being nearer to the moon than the centre of the earth O, are attracted with greater force than the earth at O (see "Gravitation," 15 and 16), and, being free to move, heap themselves in a wave directly under the moon, the water flowing towards this place; but, at the same time, the moon's attraction on the centre of the earth, O, is much greater than the water at B, owing to the same cause; hence the earth approaches towards the moon, leaving the waters behind forming a heap there, so that instead of only one tide every 24 hours and 50 minutes we have two, or one every 12 hours and 25 minutes, both occurring at the same time but on opposite sides of the globe, the 12 hours, &c., being taken up by the earth in its revolution to the place where the opposite tide took place.

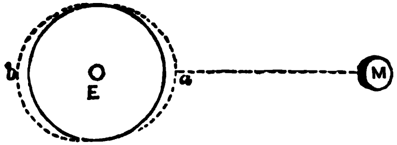

Fig. 9.

Spring and Neap Tides.—When the sun and moon are on the same side of the earth together they evidently act in conjunction. This occurs at new and full moon, causing higher or *spring tides*. But when the moon is at right angles (90°) from the sun, when she is in her first and last quarters, or half moon, his attraction, being exerted at right angles, counteracts the attraction of the moon, causing lower or *neap tides*—the proportion of spring to neap tides being as 69 to 31, or nearly as 7 to 3.

The Tidal Wave—The earth, by constantly revolving, causes every part to be offered in succession to the attracting influence, so that the rising waters are drawn along in an immense tidal wave around the globe; and had the surface of the earth been entirely covered with water the tidal wave would have been regular and continuous in its journey from east to west; but such is not the case, owing to the many interruptions of the land causing it to be deflected into various courses. The tidal wave may be regarded as receiving its first impulse in the Southern Ocean, where the greatest uninterrupted expanse of water occurs. From here it is carried northward into the Indian, Atlantic, and Pacific Oceans, where it unites with the minor tide waves generated in these oceans. It there subdivides, flows, rises, &c., according to the depth of water and the obstructions of coasts and islands. Its velocity varies much. For instance, it crosses the Indian Ocean in six hours, entering the Atlantic, travelling through it at the rate of from 500 to 700 miles an hour till it reaches the West of Ireland, reaching the Orkneys and Bergen at the same time, and travelling now as one branch through the North Sea it reaches Aberdeen in thirty-seven hours, and London twelve hours later, or forty-nine hours from the time it left its antipodes.

By noting the times at which the same high water reaches different parts of the coast a series of lines connecting these points may be laid down so as to indicate the course of the tidal wave with great precision. These series of lines are termed *co-tidal lines.* The height of the tidal wave in the Pacific seldom exceeds two or at the most three feet; in the Indian and Atlantic Oceans it reaches eight or nine feet; but in bays and gulfs, opening broadly to its course and narrowing toward the interior, as the Bristol Channel, the Bay of Biscay, Bay of Fundy, &c., it may rise from thirty to seventy feet. When the seas terminate in river estuaries, the tide, being converged, rushes up the river with great force and speed. It is then called a *bore*, examples of which occur in the Severn, where a bore rises nine feet high; in the Amazon, thirteen feet; Hooghly, twenty to twenty-five feet; Tsien-tang, thirty feet. But, on the other hand, in inland seas and gulfs, the openings of which are narrow, and lie transversely to the course of the tidal wave, little or no tides are experienced, as they are not of sufficient area to form any perceptible one of their own, examples of which are the Mediterranean, Baltic, &c.

PHYSICAL CONSTITUTION OF THE SUN.

183. Sun.—Of the heavenly bodies, the two that concern us most, as relating to Physiography, are the sun and moon, more especially the former, the centre of our universe and of this earth's annual revolution, being the source of heat and light, and the chief agent in sustaining life. The diameter of the sun is about 852,680 miles, or 107 times the earth's diameter, being equal in *bulk* (not mass) to about 1,249,500 earths; but its *mass*, or weight, is equal only to about 315,115 times that of this earth. Hence the materials composing the sun have only one-fourth the density or weight of those composing our planet, that is bulk for bulk, being about 1·43 times the density of water. The force of gravity at the sun's surface compared with the earth is 27·2.[*] The distance of the sun from the earth is calculated to be, by recent observations, about 91,430,000 miles; and from the spots on the sun it has been determined that it revolves upon its axis in 25 days 7 hours 48 minutes.

That the sun has a *motion through space* is now an established fact, travelling at the rate of 18,000 miles an hour, or 155,000,000 miles per year.

184. The Photosphere and Chromosphere of the Sun.—Whenever the sun shines we see a kind of brilliant envelope, called the *photosphere*, or light-giving surface, it being the shining surface of the sun. This is it from which we derive our light and heat. The *faculæ*, or brighter portions of the sun's surface, appear to be elevated masses of luminous matter when viewed stereoscopically; and as they remain for days suspended in the same position they are probably gaseous or vaporous. From observations witnessed during total eclipses of the sun it has been ascertained that the sun possesses an exterior gaseous envelope, of great extent, above the photosphere, probably extending more than 800,000 miles. During an eclipse, at the moment the last remnant of the photosphere is hidden by the dark moon, there appears a kind of white halo at the upper part of this gaseous envelope, or atmosphere, called the *corona*, which may be regarded as a reflection of the sun's light by his atmosphere. The lower regions of this corona is composed of layers of a greatly heated gas, of extreme tenuity, entirely surrounding the sun. This is called the *chromosphere*, and is subject to the disturbances of the photosphere, which appears to be in a constant state of agitation, causing the chromosphere to be thrown about in huge masses, in the shape of red flames, often to the height of 100,000 miles. There is supposed to be yet another layer of very highly heated gas, so hot, in fact, that metals such as iron continue in a state of vapour. Altogether it is computed the sun has no less than six successive strata of atmospheres covering its solid body.

1st. The dense non-luminous but strongly reflecting cloudy atmosphere of the penumbra.

2nd. The highly luminous photosphere.

3rd. The highly heated region of luminous metallic gases.

4th. The more light and mobile chromosphere.

5th. The self-luminous and reflective corona.

6th. The non-luminous outer corona or halo.

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[*] Gravitation proceeds from its centre. Hence, distance that bodies at the surface are removed from the centre of attraction is about 426,340 miles, and its mass, or gravity, 315,115. Hence, by the laws of gravitation (16), the gravitation of the sun, compared with that of the earth, is as the square of the radius of the sun: square of the radius of the earth :: 315,115; or as $426.346^2 : 3,956^2 :: 315,115 : 27{\cdot}2$.

The two last are believed to be some kind of a perpetual solar aurora, their luminosity being produced by electric currents.

Regarding the intensity of *heat* proceeding from the sun, it has been calculated that the annual heat is 2,381,000,000 times that received by us; and that received by the earth in one year would be sufficient to melt a layer of ice 114 feet thick all over the earth's surface. The light proceeding from the sun has also been proved to be 618,000 times that of the full moon, and equal to 5,560 wax candles at a distance of one foot from the eye.

The sun has been found, by the aid of the *spectroscope*, to be composed of similar material to the earth. Among the elements that have been ascertained may be mentioned hydrogen, iron, sodium, magnesium, manganese, calcium, chromium, barium, copper, nickel, &c.

185. Sun Spots.—On the surface of the sun spots of an enormous size are seen, some being recorded varying from 30,000 to 45,000 miles in diameter. The appearance of these spots is generally a very dark central space of tolerably regular form, surrounded by a more irregular belt of semi-luminous matter. The interior is called the *nucleus* of the spot, and the exterior the *penumbra.*

The spots are generally limited to those parts of the sun's disc a little above and below the sun's equator, forming two bands or zones. The northern hemisphere is more prolific of spots than the southern, the region of especial fecundity being from about 8° to 28° of solar latitude, both north and south. They appear in June and December to travel straight across the sun's face with a dip downwards, but in September their path appears to be sharply curved, with the convex side downwards, while in March their path is again curved, but in the opposite direction, this proving that the sun rotates upon an axis which is inclined towards the plane of the ecliptic 7° 15″. The spots have also a proper motion of their own, the rapidity of which varies regularly with their distances from the solar equator. A remarkable feature respecting them is the frequent change of form, some suddenly bursting out and rapidly disappearing, some may last only a few hours, some a few days, others perhaps three to six or more months. It has been also noticed that near places, either where a spot has disappeared, or may be expected to appear shortly, long branching streaks of light appear. These are termed *faculæ*, and are remarkable for their brightness. It is supposed they are in some way connected with the sun spots, being probably elevations in the photosphere produced by the same convulsions as the spots are. When the surface of the sun is viewed with a large telescope, the entire surface appears marked by minute irregularities. A certain mottling may nearly always be observed with telescopes of moderate power, but a higher telescopic power shows the surface to be covered with small bright dots spread irregularly. These have been called rice-grains. If higher power be applied, these bright dots will become in turn divided into congeries of still more minute points of light. These three orders of irregularity may be distinguished thus :—

1st. The *mottling* which is visible with very moderate telescopic power.

2nd. The *rice-grains*, to be seen only with a good telescope and favourable observing weather.

3rd. The *granules* which make up the rice-grains, and can only be seen with very powerful teletcopes, and when the air is still and clear.

To Professor Langley we owe the recognition of the actual structure of the rice-grains. What is termed the *faculæ*—namely, the irregular ridges of brightness—appear to have been caused by the rice-grains being crowded together. These bright patches are especially noticeable in the last stages of a spot's career. Near a spot the rice-grains appear elongated. This peculiarity is clearly recognisable in the penumbra itself, which usually consists of elongated streaks directed towards the umbra. To these elongated rice-grains the name of willow-leaves has been given. According to Professor Langley the streaks and rice-grains are identical, a rice-grain being a top view, while a streak is a side view of a long bright filament.

186. Influence of the Sun on the Earth.—Swabe, of Dessau, a German astronomer, about fifty years ago set himself to observe the sun, with especial reference to each new group of spots which made its appearance on the surface. He continued his observations for a period of forty years. He found that during some years the sun had very few spots, while on other occasions there were very many, the period from maximum to maximum, or from minimum to minimum, being a little over eleven years. Thus he found from 1828 to 1837 the number of new groups were respectively for each year 225, 199, 190, 149, 84, 33, 51, 173, 272, and 333, the years of maximum being 1828 and 1837, and the year of minimum 1833. And proceeding in this way it was found that the years of maximum occurred again in 1848, 1860, 1870, and the years of minimum 1843, 1856, and 1867.

Respecting this law of periodicity, it has been noticed that the increase in the number of spots occurs somewhat more rapidly than the decrease, about 4½ years being the usual interval between the time of minimum and the time of maximum, and about 6½ years being occupied in the gradual diminution of the spots in number until none are seen. During the time the sun is without spots, which is several months, the mottling becomes less and less recognisable, and finally for a few weeks disappears altogether. The sun's disc, which at all other times is darker near the edge than the middle, appears for a few days of a uniform brightness.

Another singular circumstance has been observed by Carrington respecting the latitude on the sun in which the spots appear at different parts of the great spot period. It is found that as the spots become less and less numerous new groups make their appearance nearer and nearer (on the average) to the equator. But after the spotless period, new groups appear at a considerable distance from the solar equation. What is the meaning of this peculiarity has not yet been recognised.

These spots are without doubt areas of great disturbances, caverns of cloud or vapour. It has been noticed that these disturbances, which are continually taking place, are greatest at the epochs of maximum sun spots. No doubt the sun's heat-giving power is intimately connected with this phenomenon. To cause a rush of air or vapour upwards we know that the gas must become specifically lighter. There must be a process of convection, the perfection of which depends on the following: (1) All gases expand greatly when heated; (2) the greater the fire the greater the expansion; (3) all bodies become specifically lighter the greater the attraction of gravity; (4) the greater the scale of arrangement the greater the rush. Thus, for instance, a large furnace attached to a tall chimney.

On turning to the sun we find—(1) *gas*, namely, a body which expands greatly when heated; (2) a very strong fire, or, in other words, very great inequalities of temperature; (3) the attraction of the sun is much more powerful than that of the earth (27·2); and (4) that the scale of arrangement is enormously large. Here we have the very elements to produce powerful convection currents, which are exceptionally strong at the time of maximum sun spots. Hence we may conclude that the sun is most powerful at these times.

One result of the sun being most powerful would be to cause the process of evaporation and condensation to become most powerful too, and hence greater rainfall. This subject has been investigated at great length by Mr. Meldrum, of the Mauritius Observatory. He found that out of 22 European observatories, where the rainfall had been systematically observed for a number of years, there are 18 at which the rainfall is greatest, on the whole, during the years of maximum sun spots.

Dr. Hunter, the Director of Indian Statistics, has pointed out that there is apparently a connection between the years of Indian famine and those of minimum sun spots, on which occasions there is very little rain over large districts of that country.

To the sun's influence we owe the winds which form, as it were, the circulating system of the earth, hence if the sun be more powerful at the epochs of maximum sun spots, we should expect the winds to be more powerful too. That such is the case has been shown by Mr. Baxendel, and Mr. Meldrum has recently discovered that there are more cyclones in the Indian Ocean during times of maximum than during times of minimum sun spots.

A similar result has also been found with regard to the hurricanes of the West Indies, and recently it has been observed that marine casualties appear to follow a cycle corresponding to that of sun spots

187. Magnetic Storms (see 35).—There can be no reasonable doubt of the connection between the state of the sun and magnetic changes. The sun spots lead the way, the magnetic phenomena following closely behind. The greater the number of spots the greater the magnetic activity. There is also reason to believe that the meteorological phenomena, as well as some of the magnetic phenomena, lay behind the corresponding solar outbreak. Hence it appears that by means of a study of the sun's surface terrestrial phenomena might be predicted.

188. Cause of the Periodicity of Disturbance on the Solar Surface.—Two theories have been proposed to account for these. Some argue that the sun somehow becomes an invalid every eleven years, and has a violent skin eruption; others regard the configuration of the planets as concerned in the solar outbreaks. Dr. Warren De Lue, in discussing this question, says: "In sun spots we have, *as a matter of fact*, a set of phenomena curiously restricted to certain solar latitudes, within which, however, they say, according to some complicated periodical law, and presenting some periodical variations, in the frequency of a strangely complicated nature." He and others endeavour to show that Venus, Mercury, and Jupiter in some way or other have something to do with this phenomena. Thus they show that there is a particularly large amount of sun spots a little before those epochs at which Venus and Mercury come together, and there is likewise a particular strong magnetic oscillation just a little after the same epochs—and the same takes place at the epochs at which Mercury and Jupiter come together.

Professor Balfour Stewart goes further. He endeavours to connect the eleven-year period to the planets. He says: "We have recently heard a great deal about intra-mercurial planets, the existence of several of which has been suspected. Now, we may argue in this way, if known planets such as Mercury produce magnetic inequalities of corresponding periods, may we not reverse the process, and search for magnetic inequalities, which may possibly correspond in period with intra-mercurial planets, which it may be difficult to detect in any other way? As a matter of fact, there are at least three such magnetic inequalities of very considerable magnitude, one having a period of 24 days nearly, another of 24·65 days, and a third having a period of 24·8 days nearly. The last two have very nearly the same period, but the faster is able to overtake the slower and act along with it every eleven years." He also further adds: "A preliminary trial gives ground for supposing that such inequalities may be found to occur in duplicate, one of these denoting possibly the period of the planet around the sun, and the other the synodic period."

THE SOLAR SYSTEM.—PLANETS.

189. When we speak of the **Solar System** we include the sun and all the bodies revolving round him: Planets with their attendant satellites, asteroids, comets, as well as the streams of meteors. The sun itself, and the earth and her attendant satellite, being the most important to us, we have already treated of them rather fully in the preceding pages. We have also enquired into the motion of the planets, and the laws governing their motion; also into the methods used for measuring their distances from the sun. Respecting their distances a curious law, first published by *Bode*, and known by his name, seemed to express them with some degree of accuracy. If the number 4 be taken and added to the products of 3, by each of the numbers of the series—1, 2, 4, 8, 16, &c., the relative distances of each of the planets is approximately found.

If distance of MERCURY = 4 + (0) = 4...True distance = 3·9.
The distance of VENUS = 4 + (1 × 3) = 7... „ 7·2.
„ The EARTH = 4 + (2 × 3) = 10... „ 10 0.
„ MARS = 4 + (2^2 × 3) = 16... „ 15·2.
„ CERES (Astrd.) = 4 + (2^3 × 3) = 28... „ 27·7.
„ JUPITER = 4 + (2^4 × 3) = 52 .. „ 52·0.
„ SATURN = 4 + (2^5 × 3) = 100.. „ 95·4.
„ URANUS = 4 + (2^6 × 3) = 196.. „ 191·8.
„ NEPTUNE = 4 + (2^7 × 3) = 388.. „ 300·6.

From the above table we see the law agrees fairly well with the true distances, until we reach Neptune. This planet entirely violates the law, hence we must consider the law simply as a chance coincidence, but it is useful as an aid to the memory.

The table given on the following page gives the distances, dimensions, weight, &c., of the planets. It is on the accuracy of the *sun's distance* from the earth that our knowledge of the sizes, distances, weight, &c., of the planets, and also of the sun, depends. Hence the importance of this problem, which will account for the hundreds of years that have been spent (records of which we have from about 400 years B.C.) in attempting to solve this question.

THE SOLAR SYSTEM.

Names and Order of the Planets.	Time of Revolution. D. H. M.	Diameter in Miles.	Mean Distance from the Sun.	Period of Revolution in Mean Solar Days.	Velocity in Orbit, Miles per hour.	Density of Specific Gravity of Earth=1.	Force of Gravity at Surface of Earth=1.	Volume of Earth=1.	Mass or Weight of Earth=1.	Mass of Sun =1.
Sun ……	25·7·48	852,584	….	..	17,583	·25	27·2	1245130·00	314760	1
Mercury ..	1·0·5	2,962	35,650,000	87·97	105,330	1·24	1·15	·052	·08	$\frac{1}{4865751}$
Venus……	0·23·21	7,510	66,614,000	224·7	77,050	·92	·91	·851	·79	$\frac{1}{390000}$
Earth ……	1·0·0	7,912	92,093,000	365·25	65,533	1	1	1	1	$\frac{1}{314760}$
Mars ……	1·0·37	4,920	139,312,000	686·98	53,090	·96	·40	·14	·13	$\frac{1}{2680337}$
Min'rPlan'ts	..	..	259,000,000	1681·89	..	..	..	..	..	..
Jupiter ….	0·9·55	88,390	475,693,000	4332·61	28,744	·23	2·54	1387·5	300	$\frac{1}{1047}$
Saturn ….	0·10·29	71,904	875,140,000	10759·22	21,221	·13	1·09	747·4	90	$\frac{1}{3501}$
Uranus ….	0·9·30	33,023	1,753,850,000	30686·81	14,963	·18	1·06	72·3	12·7	$\frac{1}{24905}$
Neptune ..	..	36,620	2,746,250,000	60127·71	11,958	·16	1·20	98·7	16·7	$\frac{1}{18780}$
Moon ……	..	2,153	….	..	2,278	·61	·17	·024	·013	1/[illegible]

THE PLANETS,—ATMOSPHERE, TEMPERATURE, &c.

190. Mercury.—Not much is at present known of Mercury, the planet nearest the sun, but it is believed to possess a dense, cloudy atmosphere, which possibly may protect it from the great heat of the sun ; it is calculated that the mean heat in Mercury is above the boiling point of quicksilver, and even near the poles water would always boil. Mountains have been seen on its surface ten miles high. The orbit of this planet makes an angle of 7° with the ecliptic. It revolves round the sun in a shorter period than any other planet. The length of its synodical period, or that in which it will pass through all its phases, from one inferior conjunction to another, is 115 days 21 hours, but its actual time of revolution round the sun, or sidereal period, is only 87 days 23hrs. 15m. 43·91s. During the synodical period the planet has a retrograde motion ; in the remainder it will have direct motion. Its mean distance from the sun is 35,392,470 miles, and the eccentricity of the orbit is expressed by the fraction $\frac{1}{4\cdot 86}$, being more than 14 millions of miles more distant from the sun at aphelion than at perihelion. (Also see Table of the Solar System.)

191. Venus.—The next planet (omitting Vulcan, of which very little indeed is known) in nearness to the sun is *Venus*, the morning and evening star, for when to the west of the sun it rises before it, being then called the "morning star," but when it is to the east of the sun it sets after twilight, being then termed the "evening star." The orbit of this planet makes an angle of 3½° with the ecliptic, and the inclination of its equator to the plane of orbit is 49° 58′. It performs its revolution in 224 days 16hrs. 49m. 8secs., but its *synodical* period is 583 days 4hrs. 48m., during which time it has a retrograde movement of 42 days. The eccentricity of its orbit is not very great, being only about one million miles between the greater and least distances from the sun.

Of all the planets Venus shines with the greatest brilliancy, being often visible in daylight, at noon. That it possesses an atmosphere of considerable density is now certain, its horizontal refraction (hence the density of the atmosphere) having been found very nearly equal to that of the earth by observing the amount of twilight upon the illuminated portion of the planet. According to Vogel, the atmosphere contains aqueous vapour. The temperature of Venus, though probably mitigated by her atmosphere, must be far too high for the existence of either animals or plants ; and also the inclination of her axis, which is affirmed to be more than 60°, would cause very great changes in the seasons.

Being near the earth, and of nearly the same magnitude as it, the effect of its gravitation is felt in its displacing the earth from its true orbit. From this effect, its mass has been calculated to be $\frac{1}{390000}$ part of the sun's. Hence, by comparing the bulk of the planet with its mass, it is found that its density is 5·36 times that of water, or very nearly equal to that of the earth. Mountains of a very great height have also been observed upon this planet, the highest summits having been estimated to be $\frac{1}{260}$ of its diameter, or more than 26 miles. Both this planet and Mercury, when viewed through a telescope, present phases like the moon.

192. Mars.—The next planet from the Sun is the *Earth*, after which comes *Mars*, the most remarkable of all the other planets—as it appears to be the only one with any probability of being inhabited excepting our earth. It also resembles our earth in one or two circumstances, namely, in its revolution, which takes very nearly the same time as our earth, 24h. 37m. The inclination of its axis to the ecliptic is also very nearly the same, about 28° 51′—and its orbit makes an angle with the ecliptic of 2°. Its surface also appears to consist of land and water, about five times as much land as water. Around the poles its surface is white, which increases in size as the winter appears in that hemisphere, and is less in summer. Hence we conclude that it has polar snows similar to our earth It is considered certain that this planet is enveloped in an atmosphere of considerable density, and its temperature, owing to its greater distance from the sun, must be colder than that of our globe, which will account for the continual snow seen on its surface. The land on its surface appears of a reddish tint, and gives rise to a the fiery appearance of the planet to the naked eye. It is supposed that this is the real colour of the soil, so that its crust is something like the red sandstone of our globe. The water appears of a bluish-grey colour. It has lately been discovered that this planet possesses two satellites.

193. Asteroids.—When Bode's Law was first announced in 1778, it was suggested that in the gap between Mars and Jupiter a planet might be found which had previously escaped detection. At this time neither Uranus nor any of the asteroids had been discovered. About three years afterwards, Uranus was discovered by Sir J. Herschel, and as it was found to accord with the law, a systematic search was made to see if a planet did not exist in the space between Mars and Jupiter. The search first resulted in the small planet *Ceres* being discovered, by Professor Piazzi, occupying the position suggested by Bode's Law. The discovery of this planet or *asteroid* was followed by the discovery of others in the same region, and at present two hundred and forty-four of these are known. The largest are Ceres, Vesta, Juno, and Pallas. Of these Vesta is the brightest, appearing like a star of the fifth magnitude, the others appearing like stars of the eighth magnitude. The diameters of Vesta and Ceres are about 230 miles each, while many of the smaller ones are less than 50 miles in diameter, and some not more than 15 miles. These small bodies evidently belong to one family, for they all revolve in orbits so entangled that it has been said that, if the orbits be imagined as material rings, the whole could be suspended by taking any one up at random.

This zone of planetoids is supposed to form a connecting link between the larger planets and the streams of meteors, having been at one time a mass of matter resembling the rings of Saturn, but, owing to their insignificant mass and great distance from the sun, the equilibrium has been lost, breaking up the ring, and forming a number of bodies each revolving in its own separate orbit. The mass of all the asteroids taken together would not form a body of the size of Mercury.

These planets, owing to their orbits being frequently more inclined to the ecliptic than those of the larger planets, are sometimes termed ultra-zodiacal. The most inclined of any is Pallas, the inclination of its orbit being 32° 42′, or about five times the inclination of Mercury. Their mean distances from the sun vary considerably, the nearest being about two hundred million miles, and the farthest more than three hundred and twenty-five million miles distant.

194. Jupiter.—The next planet, after the asteroids, is Jupiter, the largest of the solar system. When in opposition, it shines with a brilliancy nearly equal to that of Venus. It revolves in an orbit but very slightly inclined to the ecliptic, the eccentricity of which is $\frac{1}{20\cdot763}$, so that its greatest distance from the sun is about 500 million miles—(see table)—and least distance about 450 millions. From the particulars given in the table it will be found that the bulk of Jupiter is 1,290 times that of the earth, and its mass about 300 times the earth's mass, its density being less than one-fourth the earth's density, and therefore about 1·32 as compared with water. Its disc is usually crossed by dark-coloured belts, or cloud belts, parallel to its equator. This planet is surrounded by a dense, cloudy atmosphere, which is capable of reflecting the solar light. The dark belts are, probably, openings in the clouds, through which we see the darker surface of the planet, or, more probably, lower beds of clouds beneath. These belts continually change in number and size, and are supposed to be caused by violent permanent winds. There are also to be seen occasionally small bright spots, resembling patches of floating cloud, which have been supposed to be masses of cloud floating round about the summits of high mountains. Jupiter's time of revolution, or day, as determined by these spots is 9h. 55m. 50s. Its velocity is thus very great, and the centrifugal force generated at the equator must likewise be very great, hence we should expect a very considerable polar compression. Such is the case, as a glance through a telescope shows. The ellipticity is calculated to be $\frac{1}{13\cdot71}$, so that the polar diameter is 6,450 miles less than the equatorial diameter.

Jupiter's year consists of 4332·58 mean solar days, while its synodical period, or the time between two successive similar conjunctions* is only 398·8 days. In the case of the inferior planets the synodical period is greater than the sidereal period, or the time of one complete revolution round the sun, owing to the sun advancing in the heavens in the same direction with the planet, only slower, so that the latter has more than a complete sidereal period to perform to come up with the sun again. In the case of the superior ones, with the exception of Mars, the synodical period is less than the sidereal. Its orbit makes an angle of 1⅓° with the ecliptic, and the inclination of its equator to the plane of orbit is 3° 4′. It is attended by four satellites, or moons, revolving round it from west to east, similar to ours—(see Satellites)—forming, as it were, a miniature system, confirming the laws of Kepler, which are observed to apply as ccurately to the periods and distances of the satellites as to those of the principal planets.

Respecting the temperature of this planet, it is considered to be a mass of heated matter, cooling slowly, being probably still either in a liquid or gaseous state. Its satellites being comparatively very small bodies, would cool much more rapidly, so that their mass would be heavier than that of their own primary.

195. Saturn.—The next planet is *Saturn*, whose mean distance from the sun is about 872 million miles. Its eccentricity is $\frac{1}{17\cdot989}$, hence its greatest and least distance may vary by about fifty million miles. It requires nearly 29½ years to make its circuit round the run. This slow motion allows the earth to come a second time between the planet and the sun in little more than a year, or, in other words, its synodical period is 378 days. This planet has a most remarkable appendage, namely, a luminous ring, or rings, by which he is generally seen to be surrounded. The general appearance of these rings is that of three lying outside of each other in succession, the two outer ones being the brightest, and the inner one appearing transparent, and only just visible with a large telescope. The diameter of the outer ring is 166,000 miles, but not above 130 to 140 in thickness. Of what kind of matter they are composed has long been a disputed question. That they cannot be solid is certain, as to preserve equilibrium it would be necessary that the parts near the planet should revolve much more rapidly than the more distant regions. Such a motion would at once tear a solid in pieces. The generally accepted theory is that they consist of millions of small satellites revolving round the primary planet. Thus the inner ring, from its semi-transparency, seems composed of these small bodies, but not so thickly strewn but that we are able to see through the interstices, while the other rings, which appear brighter, are composed of denser streams of such small bodies.

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* A planet is in conjunction when it has the same longitude as the sun, or passes the meridian at the same time, and in opposition when it is distant in longitude from the sun by 180°, or when it passes the meridian at midnight.

Regarding these rings Sir J. Herschel, in his valuable work, writes: "They must present a magnificent spectacle from the regions of the planet which lie above their enlightened sides, as vast arches spanning the sky from horizon to horizon, and holding an almost invariable position among the stars. On the other hand, in the regions beneath the dark side a solar eclipse of fifteen years in duration, under their shadow, must afford (to our ideas) an inhospitable asylum to animated beings, ill-compensated by the faint light of the satellites. But we shall do wrong to judge of the fitness, or unfitness, of their condition from what we see around us, when, perhaps, the very combinations which convey to our minds only images of horror may be in reality theatres of the most striking displays of beneficent contrivances."

Saturn appears to have an atmosphere dense and cloudy, similar to that of Jupiter, and is attended by eight satellites. Its orbit makes an angle of 2½° with the ecliptic, and the inclination of its diameter with the plane of orbit is 26° 49'.

196. Uranus.—The next planet we come to is *Uranus*, of which very little is known; but it is worthy of note that its distance is so great that the light and heat it can receive from the sun is only $\frac{1}{368}$ part of the intensity on the earth. It requires about 84 years to perform its revolution round the sun, while it turns upon its axis in 9½ hours. The mass of this planet has been calculated in various ways, the most trustworthy estimate being $\frac{1}{24605}$ of the sun's; hence, from the diameter given in the table, and assuming the planet to be spherical, its density as compared with the earth is ·174, and as compared with water ·99, so that it is slightly heavier than Saturn, but not so heavy as Jupiter. It has probably a considerable temperature, being to a certain extent self-luminous. Four satellites have been discovered in attendance upon this planet, but their motion is different from those belonging to the other planets, being retrograde. The plane of their orbits is inclined to the ecliptic at an angle of 78° 38′, or not far from perpendicular to it. The angle Uranus makes with the ecliptic is 47′.

The greatly increased power of telescopes of the present day has enabled astronomers to do something more than see in Uranus a dull red disc. In a paper read before the Paris Academy of Sciences, Mr. Henry notified the discovery of two grey belts, straight and parallel, placed symmetrically with respect to the centre of the disc of Uranus, and inclined at about 41° to the direction of the orbits of the satellite. He assumes that the planet's equator is in the direction of the belts. Belts were also observed by Professor Young—two on each side of the equator. The general trend of the belts appeared to make an angle of about 30° with the major axis of the satellite orbits. According to several observers Uranus exhibits considerable flattening at the poles, some of them giving a result of $\frac{1}{14}$ for the ellipticity, but Professor Young does not attribute any great weight to this value, thinking it probably too large.

197. Neptune is the most distant of all the planets. It shines like a star of the eighth magnitude. It has only one satellite at present discovered, but probably it has more. Owing to its great distance from the sun it will shine upon it with only $\frac{1}{900}$ part of its intensity on the earth. Inclination of orbit 1° 47′, and of diameter with plane of orbit 26°. The orbit described by Neptune requires about 164½ years for its completion, the mean distance from the sun being 2,746,250,000 miles. Its mass has been calculated to be $\frac{1}{18780}$ of the sun's, hence its density as compared with the earth is ·15, and compared with water ·848, being about the same as that of Uranus.

With the exception of Mars, all the superior planets are supposed to be in a gaseous state, having not sufficiently cooled yet to become solid. From the above short description of the planets we see that none of them are favoured like ours. It is situated at a *medium distance* from the sun, so that we are exempt from the extremes of heat and cold. Again, its orbit lies in the plane of the sun's equator, but the others are inclined more or less to it. The only other planet that appears to have the slightest possibility of being inhabited is Mars, and there the cold must be as severe in their summer as it is in our arctic and antarctic regions. (For distance of planets from the sun, their sizes, density, times of rotation, &c., see Table of "Solar System.")

198. Satellites.—With the exception of the satellites of Uranus, they all revolve round their primaries from west to east, and rotate on their axis in the same direction as their primaries, and also in exactly the same time as their times of revolution round those bodies. The most interesting of the satellites to us is evidently our own. (For description and particulars see 177.)

The *density* of all the satellites has not yet been ascertained. Those known are the moon, ·61, or a little over ⅗th of that of the earth; Jupiter's four average about ·288, or a little more than ¼th of that of the earth. Those of Saturn are supposed to be about ·134, but very little is known for certain. It has lately been ascertained that .

Mars possesses two satellites—one at a distance of 14,000 miles, revolving round the planet in 30¼ hours, and another at 5,600 miles, and revolving at the rate of 7⅝ hours. Their planes of orbits are very nearly coincident with the equator of the primary, while the eccentricity of the outer one is so small that practically the orbit may be taken as circular. On the other hand the inner moon shows some approach to a decided eccentricity. They have been named—the outer one Deimos, and the inner Phobos. The latter is the brighter of the two. To an observer on Mars, Phobos will move through an arc of 47° in an hour, and will present the curious phenomenon of a moon rising in the west, meeting and passing the outer moon, whose motion is not quite 12° in the hour, and setting in the east. The satellites are without doubt the smallest heavenly bodies ever discerned by the human eye, and their discovery adds another link to the harmony of the solar system, for, so far as we have yet been able to ascertain by the aid of telescopes, the number of moons attendant on the planets increase accordantly with their distances from the sun. Thus the earth has one satellite, Mars *two*, Jupiter twice two, or *four*, Saturn twice four, or *eight*.

Jupiter's four moons are designated respectively I., II., III., and IV. Their magnitudes and periods are as follows :—

	Period of Revolution.	Diameter in miles.	Distance from Jupiter in miles.	Mean apparent diameter.	Mass compared with the Earth.	Density compared with the Earth.	Specific Gravity.
	h. m. s.						
I.	1 18 28	2,352	267,880	1″·02	·00521	·2016	1·143
II.	3 13 15	2,099	425,156	0″·91	·00699	·3738	2·120
III.	7 3 48	3,436	678,393	1″·49	·02661	·3267	1·853
IV.	19 16 32	2,929	1,192,823	1″·27	·01283	·2515	1·426

From which it appears their periods are considerably less than that of the earth's satellite (27d. 7h. 43m.), and, with the exception of II., they are of greater magnitude than ours. Their densities average about ·288, or a little more than a fourth of that of the earth's. Their orbits are but very slightly inclined to the plane of Jupiter's equator, hence they in their rapid revolutions round him originate many eclipses, occultations, and occurrences of similar nature. Transits of the satellites take place as they come into that portion of their orbits situated between Jupiter and the earth. They then appear upon the disc of their primary as dark voluminous spots. It sometimes happens that all the four moons are rendered temporarily invisible. Thus, one is eclipsed in the shadow cast by the planet, another is occulted by his globe, while the two remaining are in front of the planet, hidden in the cloud belts.

These satellites afford by their eclipses a readily available method of determining the longitude—(see "Longitude")—and the progressive motion of light was also first ascertained by the same means.

Saturn is now known to be attended by eight satellites, to which the names of Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, and Iapetus have been given. The nearest of these is about 120,000 miles from the primary, while the most remote is 2,000,000 miles distant. The largest and best known is Titan, which is supposed to be very little inferior in size to Mars. Its orbit is also materially inclined to the plane of the ring, with which those of all the rest nearly coincide.

COMETS AND METEORS.

199. Comets, like planets, revolve round the sun, evidently under the influence of the law of gravitation, but their orbits are much more elliptical, though always identical with one of the conic sections, and obeying Kepler's second law—namely, of the equal description of areas—as the correct predictions of their return show.

The inclination of the orbits have all degrees of magnitude, and their motions in their orbit are as often retrograde as direct. Sometimes one approaches near to the sun, and afterwards recedes to a distance of many hundreds of times the distance of the earth from that luminary. For instance, the periodical comet of 1680, whose period is 575 years, approaches to within one-sixth part of the diameter of the sun from its surface, and when farthest away its distance exceeds 138 times the distance of the sun from the earth. It is also calculated that the period of the great comet of 1811 is 3,065 years. The orbits of the great majority differ very little if any from that of a parabola during the time they are visible to us. Hence we conclude that they will not return to the sun; or that the distances to which their orbit extends is so enormous as to require the lapse of ages to perform their revolution. At the same time there are a few others which recede only a very short distance in comparison—as in the case of Encké's, whose orbit is within Jupiter's, appearing every 3¼ years; Biela's, appearing every 6⅔ years; Faye's, 7½ years; Winnecke's, 5½ years; Brorsen's, 5·58 years; D. Arresi's, 6⅔ years; and Halley's, 76⅓ years.

Their form generally consists of three parts—the *nucleus*, or brightest and densest part; the *coma*, a nebulous haze or cloud surrounding the nucleus like an atmosphere; and the *tail*, a conical appendage, stretching often to immense distances, and mostly in opposite directions to the sun. Some comets appear without tails.

200. Regarding their constitution not much is at present known, but it is found by telescopic observations, and also by the insignificant effect produced on the motions of planets when comets approach near them, that the masses of all the known comets are exceedingly small, even of incomparably less density than our atmosphere, or of any gas with which we are acquainted; as, through even the densest part, the faintest stars may be seen—though a slight fog near the surface of the earth prevents stars of the first magnitude from being visible.

According to some, comets consist of an immense assemblage or stream of planetary atoms, so that the solar rays will be permeated amongst the whole mass, hence causing it to appear luminous throughout the entire range of its denser portions. Of the comets of shorter period that of Biela is remarkable; thus, at its return in 1843, it was observed to divide into two distinct parts, which also reappeared in 1852, following different paths, since which date it has not reappeared. Hence the question naturally arises, what has become of it? The most feasible answer is this: "Further divisions of its materials may have taken place, dispersing the original mass over a long range of the orbit, so that the only visible remnants of this singular body are occasionally seen as shooting stars on the night of November 27, when the earth makes a very near approach to its orbit." *

The other short periodical comets appear to be in process of wasting away, for at successive returns the same comets show decided evidence of decreasing brilliancy. Hence it is conjectured that their materials are becoming distributed along their orbits, and will follow the example of Biela and become wholly invisible when the central mass has been broken up and scattered into meteor orbits.

Respecting the luminous tail, Professor Tyndall, by ingenious experiments, suggests that it is simply due to a chemical action of the light transmitted through the nucleus; or, in other words, that it is merely a spectral appearance, and not a distension of the comet's material. This idea would seem supported by the generally observed fact that the tail flows in a *direction away from the sun*, but it has also its objections. Another theory is that "a repulsive force originated by the sun has the effect of distributing the outlying materials of the nucleus into trains of different curvatures." Objections may also be urged against this.

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* Denning.

201. Meteors and Meteorites.—In close connection with comets are meteors and meteorites—the spectrum analysis showing a similar identity of materials agreeing with the constituents of the sun and of the planets. These meteors are of various sizes, but are too small to be visible by reflected light. They appear as groups or clouds, each one of which pursues a definite and fixed orbit, which are similar to the orbits of the comets—the latter being now considered as clouds of meteorites. On entering our atmosphere they are known as SHOOTING STARS, sometimes exploding in their passage through, owing to the rapid motion with which they strike the particles of air. They are then termed *fire balls*. Sometimes the fragments of these explosions fall to the earth as *meteorites or aerolites*.

The groups of meteors sometimes come in the track of the earth, so that when the earth passes through or near the track of one of them we have a *star shower*. These showers are greatest between August and November. The maximum brilliancy occurs every 33¼ years, and then sometimes for four or five years in succession there are showers of unusual brilliancy.

It has also been shown within the past few years that meteors or falling stars are bodies which travel in flights or streams around the sun, and that some, if not all, of these meteoric systems travel in the same track as certain known comets, hence we presume they are in some way associated with them. Thus the grand meteoric shower of November 13th, 1866, aroused general attention, and the result of investigation shows that these phenomena are probably *allied very closely to comets*, being in fact minute planetary bodies revolving round the sun.

The Italian astronomer Schiaparelli found that the elements of some of their orbits coincided with certain periodic comets. Thus Tempel's comet, which appeared in 1866, has a period of orbit identical with the stream of meteors which cause the November showers. Another stream of meteors has been found identical with Biela's comet; while another, a comet observed in 1862, has an orbit identical with the meteoric stream which causes an annual shower of shooting stars in August. Thus it appears that the tracks of comets are thickly strewn with particles of matter, and when the earth in its orbitual revolution comes in contact with them, they fall with great velocity towards its surface. The friction of our dense atmosphere, acting as a resisting medium, ignites the combustible matter of their composition, and renders them visible to us as luminous objects in rapid motion. They become partly dissipated in vapour and partly frittered away as harmless dust in the atmosphere, and, having lost their specific gravity, only rarely penetrate it to sufficient depth to reach the earth's surface. The chemical analysis of those larger masses which have reached the earth shows that they contain iron, nickel, cobalt, copper, tin, chromium, and various silicious compounds. The spectrum analysis of meteors has also indicated the presence of oxygen, hydrogen, sulphur, phosphorus, carbon, aluminium, magnesium, calcium, sodium, potassium, manganese, titanium, lead, lithium, and strontium. (See also "Spectrum Analysis.")

It may be noticed that shooting stars have certain definite places in the heavens whence they come, though they may travel to all parts of the sky, and if their apparent paths are attentively watched they will be found to diverge from a focus of intersection. This is called the *Radiant* Point. Many of these have been determined, so that it is very probable there are a great number of rings of meteoric matter revolving round the sun similar to that which gives rise to the November showers. Altogether several hundreds of well-marked showers have now been ascertained with precision, and every year adds to the number of such systems.

While on the subject of meteors we will just draw attention to the ideas of Mr. R. A. Proctor on this subject and the *growth of the earth.* His opinion is that the earth is, has always been, and, so long as it shall exist as a part of our cosmical system, must ever continue to be, growing in size. Meteors are bodies composed of extra-terrene matter, which travel in vast belts and in highly eccentric orbits round the sun. These systems of meteors or belts are very numerous, and when their orbits intersect that of the earth they are brought within the influence of its gravitation, and on entering our atmosphere become luminous and fall to the surface of our planet. In the periodical showers of shooting stars which are so well known, not a night passes in which some falling stars are not seen, and in certain months and on particular nights the golden rain is incessant. Of course, too, meteors fall in the daytime, though unseen. It has been calculated, says Mr. Proctor, that hundreds of thousands of these extra-terrene bodies become incorporated with the earth every 24 hours, and four hundred million in the course of a year. These may vary in weight from a few grains to a ton. One is known to have fallen in South America weighing 15 tons. Yet these small accretions to the earth's matter would take many millions of years to add a single foot to its diameter.

It has been suggested that it is to these meteors, &c., that the sun owes its continuation of heat and light, there being an incessant flow of cosmical matter and aerolites towards the sun, which absorbs them, and is thereby enabled to continue its emission of light and heat. Accompanying the sun there is a hazy nebulous cone of light, which indicates the existence of a mass of material particles, supposed to be myriads of meteors revolving round the sun in spiral orbits and continually falling into it.

Sir W. Thomson supposes that these have to make their way through a resisting medium of increasing density as it approaches the sun. Thus the friction arising from the rapid motion of each particle through this medium will render the particle itself incandescent, and the heat thus generated will contribute to the sun's heat.

FIXED STARS AND NEBULÆ

202 Number and Distance of the Stars.—The stars which are popularly called *fixed*, on account of their appearing to preserve year after year the same relative position in the heavens, are really not so, as the greater part, if not all, have *measurable* motions of their own.

The stars being at such enormous distances from us are distinguished only by their different degrees of brightness or magnitude, as it is generally termed, and from this difference they have been separated into classes, the brightest being said to be of the *first magnitude*, the next of the *second magnitude*, and so on to the *sixteenth magnitude*, which requires the *most powerful telescope* to view them. Those visible to the naked eye are included in the first six classes, and number nearly 5,000 near the equator. Very seldom more than 3,000 can be seen at once in this country. Of these only 20 are classed as of the first magnitude, the brightest of which are Sirius, Canopus, Alpha Draconis, Arcturus, Riga, Vega, Capella, and Aldebaran. Of the second magnitude there are betwee 60 and 70 visible to us, about 190 of the t ird, and 425 of the fourth.

Though 5,000 is the greatest number of stars that can be seen with the naked eye, there are visible through the best telescopes thousands of millions, the number seen being estimated at between four and five hundred thousand million. Those that can be seen with an ordinary good telescope number about twenty million, and of these eighteen million occur in what is known as the *Milky Way*, namely, that zone of faint light which stretches from the horizon on one side nearly over our heads to the horizon on the other side.

As previously mentioned, these fixed stars, as they are termed, have motion similar to the planets and satellites of the solar system, and are kept in their relative positions by the same force, viz., gravitation, which binds the members of the solar system together. As a general rule it is found that the stars of the first and second magnitudes have the largest *proper motion*, though there are exceptions to this rule. Some of them have an annual motion proper of even as much as 8″. The two stars of 61 Cygni, of the sixth magnitude, have an annual motion of 5¼″. To calculate **the distance of the stars**, the same method is adopted as is used to ascertain the size of the earth. Thus a base line was first measured, and then the angles made by viewing an object from either extremity of the line were noted, from which data the distance of the object could be calculated. Again, the same method was applied to ascertain the distance of the moon, in which case the base line was the earth's radius. In calculating the distance of the stars a much longer base line still is used, namely, the diameter of the earth's orbit round the sun, or the distance in a straight line between the place in the orbit where the earth is in winter and where it is in summer, namely, twice the distance of the sun from the earth, or about 183 million miles. Even with a base line of such an immense length, the change in position, when the stars nearest are viewed from either extremity, is so minute as not to be perceptible without the aid of the most delicate and powerful astronomical instruments.

The annual parallax—that is the angle which the radius of the earth's orbit subtends at the distance of the star 61 Cygni—is about ⅓″ of space = 206,265 × 3 = 618,795 times the radius of the earth's orbit, or distance from the sun, = 92 million × 618,795 = 56,929,140 million of miles. The probable nearest fixed star is *Alpha Centauri*, which subtends an angle of 1″ very nearly. Hence its distance is 206,265 times the radius of the earth's orbit = 18,976,380 million miles. The parallax of Sirius is only 0″·150, so that its distance = (206,265 ÷ ·15) = 1,375,100 times that of the sun. Another whose distance has been measured is *α Lyræ*, the parallax of which is about one-fifth of a second, or five times the distance of the star *α Centauri*.

203. Regarding the Magnitude of the Stars we have no certain evidence at present, though astronomers believe that many are far superior in size to ours. Thus Dr. Wollaston, by direct photometrical experiments, has ascertained that the light of Sirius, as received by us, is to that of the sun as 1 to 20,000 million. Hence the sun, in order that it should appear to us no brighter than this star, would require to be removed to 141,400 times its actual distance. It has been proved that the distance of Sirius cannot be so small as 200,000 times that of the sun, so that upon the *lowest possible computation* the light really thrown out by Sirius cannot be so little as double that emitted by the sun; and assuming a much lower limit of *possible* parallax in Sirius, or a distance of 1,375,000 times the sun distance, which is its distance according to recent calculations, the intrinsic light of Sirius must be nearly fourteen suns—or, in other words, Sirius is equal in magnitude and splendour to fourteen suns. Taking into account his small companion, it has been calculated that their masses together are nearly twenty times that of the sun. And more extraordinary still is the case of Procyon, which, with its small attendant, contains probably about ninety times the amount of matter in our sun.

These mighty masses, which shine by their own light, are doubtless suns, which may, perhaps each in its own sphere, be the presiding centre round which planets, or bodies of which we can form no conception, may be circulating. It was supposed by Madler that the solar system might be only one of a great system of suns revolving round their common centre of gravity, or even round one great central sun; and he was led to suppose that this central luminary might be *Alcyone* or *η Tauri*, the brightest of the Pleiades.

Though the stars are distant suns they are not all *exactly* like ours, as an examination of them shows. Among the *very bright* ones some appear to have more simple atmospheres than our luminary—namely, they do not contain *all the elements* found in the sun. Among the stars which are not so bright—especially those whose *light appears of a reddish hue*—the atmosphere seems very different from that of our sun; so much, indeed, that it is supposed that such stars are *colder* than our sun.

204. Variable Stars.—One of the most interesting of the phenomena that is observable in the stars is that of the periodical variation of brilliancy belonging to some of them. Thus, in the time of Tycho, a star suddenly appeared in the constellation Cassiopeia, whose brightness exceeded that of stars of the first magnitude, and equal to that of Venus when nearest the earth. Its brightness decreased very rapidly, having died, as it were, entirely out in sixteen months. Some stars complete their period of variation in a very short time. For instance, Algol requires only 69 hours. During nine-tenths of the time it appears as a star of the second magnitude, and then changes till it becomes one of the fourth magnitude, the remaining one-tenth of the 69 hours being taken up half in decreasing and half in increasing its brightness. Another remarkable instance is β Persei, whose period of change is about 2 days 20 hours 49 minutes, during which time it varies in brightness from that of the second magnitude to the fourth, continuing in its brightest state for 2 days 13 hours, the remainder being occupied in decreasing and increasing. Another instance is δ Cephei, whose period is 129 hours. β Lyræ's period is 156 hours. A list of between 200 and 250 have been collected. That observed by Tycho properly belongs to the "temporary" class, a remarkable one of which burst suddenly out in May, 1866, equal in brightness to the stars of the second magnitude, and declined from this to that of one of the twelfth magnitude in twelve days. Four days after the first appearance of this star Dr. Huggins and Dr. Miller examined the spectrum, which was found to consist of two distinct parts, or rather there were two distinct spectra, one of which was formed of four bright lines, and the other was analogous to those of the sun and stars. The bright lines in the spectra showed that it had its origin in incandescent gases, and the position of these lines showed that hydrogen was one of these. Hence it is imagined that the star became suddenly enveloped in the flames of burning hydrogen.

205. To explain the phenomena exhibited by the periodical stars several hypotheses have been suggested, one of which endeavours to account for the variations in magnitude by supposing that opaque bodies are revolving round these particular stars, and that at certain times they are interposed between the earth and the star, and so cut off from us a portion of the luminous rays of the latter. Another hypothesis suggests that the stars themselves may have portions of surface of unequal reflecting power, and that in their revolutions they present to us in turns these more or less bright parts, and so cause the variations that we observe. This theory fails to explain the changes observed in the Algol type, being only applicable to such as are quite regular in their fluctuations. A third supposition is that the stars may be subject to periodic changes similar to those which produce sun spots ; indeed, Professor Stewart is of opinion that our sun is a variable star with a period of about eleven years.

Professor Pickering attempts to show that none of the theories put forward to account for the variability of the light of such stars as Algol will satisfy the observed changes except that of an opaque satellite ; and, adopting this theory in his paper on Algol, he finds theoretically such a satellite, whose position and movements agree with the observed facts.

There is also another class of stars—namely, *double and multiple stars*, the most remarkable of which are 61 Cygni and γ Virginis in the Northern Hemisphere, and α Centauri in the southern. This class consists of those stars that go round each other, and are termed double, or multiple, according as there are two or more moving around each other. They are said to be *physically connected* with each other, being so close that one revolves round the other, as we revolve round the sun. The shortest known of these periods of revolution is 36 years. The number of these systems at present known is 800.

206. Colour of the Stars.—The colour of the stars varies greatly, as when seen through a telescope some are red, some orange, or yellow, while the smaller companion stars generally appear blue, violet, green, &c. When they appear as *double stars*, or *binary systems*, the two are generally of different colours—namely, complementary. Thus, if the larger of the two be of a yellowish colour the lesser one will appear bluish, but if the colour of the former be crimson the latter will be of a greenish hue, and so on. Sir J. Herschel was of opinion that these colours might possibly not be the result of contrast, but of light differently tinted.

Among the stars that are *white* may be mentioned Sirius and Capella. *Ruddy*—Aldebaran and Antares. *Yellow*—Arcturus and Pollux. *Orange*—β Cygni (the larger). *Blue*—β Cygni (the lesser). *Red*—Betelgeux.

207. Classification of Stars according to their Spectra.—The spectra of many of the fixed stars differ very little from that of the sun. Dr. Huggins devoted great attention to the spectrum of Sirius (the brightest of the fixed stars), which he found to be a continuous one, crossed by a number of dark lines, which are disposed at pretty equal intervals through its whole length. The series of colours correspond so far with that of the solar spectrum that the combination of the whole gives out a white light. The spectrum of this star corresponds with that of the sun by presenting four strong lines. The spectra of all the stars yet examined, with the exception of two, show the presence of hydrogen—viz., one of the chief constituents of the sun; and sodium, calcium, iron, and magnesium are often recognised. In Aldebaran, bismuth, mercury, antimony, and tellurium have also been recognised. So that we may state generally that the fixed stars have a composition resembling that of the sun. An examination of the spectra shows that they generally are identical with that of the sun, though very minute differences have appeared. From these astronomers have been able to divide them into four classes or orders according to their temperature, the first being the hottest. The *first* includes those which shine with a *white light*, which consists of the greatest number by far, including such stars as Sirius and Vega. Their spectra show all the seven colours, crossed by the four lines of hydrogen and many others. The *second* class includes those whose light is *yellow*, having spectra crossed by numerous fine dark lines, resembling those of the solar spectrum. To this class the sun belongs. The small remaining portion consists of orange and red stars, which form the *third* class. Their spectra have *bright* lines in as well as dark, and appear something like that of the spots of the sun. The *fourth* class consists of the third class arranged in bands, and embracing the faint stars.

208. Star Clusters, Nebulæ.—Small local aggregations of stars exist in many parts of the heavens. These, when viewed by the naked eye, appear as hazy spots of light, but when aided by telescopic power they are seen to be clusters of stars. Several thousands of these groups lie scattered over the heavens, and especially in a broad zone crossing the galaxy, or milky way, at right angles. In some of the groups the stars are so densely packed, and are so very minute, that it requires a very powerful telescope to show that they are composed of separate individual stars, and some groups even defy the highest telescopic power that can be brought to bear upon them, still appearing as faint milky patches resembling cloud. These *irresolvable groups* are termed *nebulæ* (*nebula* meaning a little cloud), the spectroscope proving that they are merely cloud-like masses, and not star clusters. The *zodiacal* light, which may be seen soon after sunset, about the months of April and May, or at the opposite season before sunrise, as a cone or lenticular-shaped light, extending from the horizon obliquely upwards, and following generally the course of the sun's equator, is supposed to be of the nature of nebulæ, thus placing our sun in the list of nebulous stars.

According to some astronomers we live in a *star-cluster* similar to those nebulæ which can be resolved. Thus the twenty million stars which may be seen by the aid of the telescope form but one cluster out of the thousands, perhaps millions of groups scattered through infinite space. Mr. Proctor does not agree with this theory. He is of opinion that all the nebulæ and star-clusters exist within the limits of the sidereal system. Thus he says: "It seems to me that within certain regions of space stars of many orders of real magnitude are gathered together. All the star cloudlets hitherto discovered, gaseous or stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the sidereal system. They all form part and parcel of that wonderful system whose nearer and brighter parts constitute the splendour of our nocturnal heavens. I reason thus because I have been led to the conclusion that our sidereal system is much more extensive than has hitherto been supposed. It is not that I draw the nebulæ inwards to the star depths, but that I extend the star depths outwards so as to include the nebulæ." *

Respecting the wonderful scene presented by the star-depths, he remarks: "Let our thoughts pass from our earth, which seems so magnificent, to the giant orbs of Saturn and Jupiter, which dwarf her dimensions to insignificance, thence to the sun, compared with which the largest planets seem so small. Then let us consider the dimensions of the solar system, compared with which even the dimensions of the sun are as nothing. Next let us pass on in thought to the vast region of space within which our whole solar family is travelling. Then let us picture the scheme of suns, of suns of which our sun is a member—not the sidereal system, scarcely even an appreciable fraction of that system, but the particular family of suns to which the sun belongs—and let us consider how the domain of the sun, the region of space over which he bears sway, is in its turn reduced to mere nothingness by comparison with the scheme of suns of which our sun is a member. Then, lastly, let us picture to ourselves that the scheme of stars to which our sun belongs is but one of the atoms of which the frame of the sidereal systems is built."

209. The Nebular Hypothesis.—The hypothesis of Kant, the great German philosopher, was that all the planetary bodies of the solar system rotating and revolving in the same direction appear to have been created together, and that their motion was given to them by a single impulse. Other hypotheses have been suggested, the chief of which is that of Sir W. Herschel, which supposes that all sidereal bodies are continually growing, and other bodies forming from the aggregation of nebulous matter. Thus a nebula in its first stage gets continually smaller and rounder, getting hotter and hotter all the time, and condensing and contracting until it becomes a nebulous star, leaving rings of vapour round its equator like those of Saturn, eventually breaking and forming a globular mass of vapour, which gradually cools until at last it becomes a planet. As the rate of contraction diminishes it shines like a sun, giving light and heat to planets like ours that have become cool and habitable. These stars, after shining first as bright stars, gradually lose their brightness, becoming dim, or, perhaps, red, as in the case of Jupiter and Saturn, which have the appearance of expiring suns, no longer shining with their former vigour.

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* Manchester Science Lectures.

THE PRINCIPLES OF THE SPECTRUM ANALYSIS.

210. This **analysis** *reveals the chemical elements of a body by the character of its spectrum when reduced to a state of glowing vapour.* When a beam of solar or white light is caused to pass through a prism the beam is refracted, and also separated into its constituent parts, a phenomena which is called *dispersion.* Sir Isaac Newton admitted a sunbeam through a small circular aperture in the shutter of a darkened room. When there was nothing in the way to prevent it, the ray of light formed a straight line, causing an image on the floor; but on making the beam to pass through a horizontal prism the rays were refracted, and formed on the wall or screen seven beams of colour, namely (commencing from the bottom) red 12, orange 7, yellow 12, green 27, blue 27, indigo 11, and violet 33—the numbers representing the proportionate parts of the colours in the spectrum. The elongated image on the screen is called the *solar spectrum.* Besides these coloured rays there is an invisible space below the red, where the heat is greater than in any other part, and a space above the violet, where the chemical effect is greater. The invisible rays below the red are termed *heat rays*, or the *less refrangible rays*, and those above the violet *actinic rays*, or the *more refrangible rays.* The yellow rays give the most light. Now suppose, instead of a beam of solar light, the light from a solid or liquid body white with intensity of heat, say a candle for instance, is made to pass through the prism, the white light is spread into a *rainbow*-tinted streak or spectrum, in which there is no break, it being imperceptible where one colour begins and another ends. In other words, no tints are wanting in the light from a *glowing solid* or *liquid matter.* Its spectrum is therefore perfect, or *continuous* as it is technically called. The spectrum of the light from the sun does not accord with this. It is not continuous, not containing all the tints of the rainbow.

On a careful examination through the telescope it will be observed that the different colours are crossed by a great number of dark lines, not absolutely black, but of different degrees of blackness. These are know as Fraunhofer's lines, so named from the German optician who first accurately observed and mapped out the position of 876 of them, in 1815. The real discoverer of these lines was our own countryman, Dr. Wollaston, in 1802, when he discovered two lines with his naked eyes. These lines occur in groups of fine lines, with an occasional thick one, their order being always the same. Of the more conspicuous lines Fraunhofer chose eight, which he denominated A, B, C, D, E, F, G, and H, to compare the rest with. A, B, and C are single dark lines in the red, D is a double line between the orange and the yellow, E a group of fine lines in the green, F a thick black line at the commencement of the blue, and G and H two groups of fine lines in the indigo and violet.

Between A and B is a band of several lines called a. Between B and C Fraunhofer counted nine fine lines; between C and D thirty; D and E eighty-four. E is a band of several lines, the middle one being stronger than the others. Between E and F, namely, at b, there are three strong lines. Between E and b Fraunhofer counted twenty-four lines, and between b and F more than fifty. Between F and G, and between G and H, Fraunhofer counted 185 and 190 lines respectively. Altogether he counted and mapped no less than 576 dark lines. What these dark lines really mean was naturally the next problem Fraunhofer attempted to solve. He examined sunlight reflected in various ways, as from the moon, the planets, from clouds, the sky, terrestrial substances, and so forth, and found in every case exactly the same lines as he had seen in the *solar* or *prismatic* spectrum. He also examined the light from the fixed stars, and found that each star gives a spectrum showing the prismatic colours, though none of these spectra are exactly like the solar spectrum, some of the lines in the latter being wanting in the former, while others are not so strongly marked, and some of the lines to be seen in the star spectrum are not to be seen in the solar spectrum. When the source of light is a candle or lamp the spectrum shows only two dark lines, or rather one double, in the same place as the double line D of the solar spectrum. We thus find from this that various sources of light give different spectra. Thus solid and liquid bodies *glowing with intensity of heat* give a spectrum without dark lines or gaps of any sort, or what is called a continuous spectrum. But it will be noticed the spectrum varies with different temperatures. For instance, if a piece of iron is gradually heated, the red end of the spectrum begins to be seen as soon as the iron reaches a dull red heat. As the heat is increased, the orange and yellow parts are seen, and at length, when the iron has reached a white heat, the whole rainbow spectrum from red to violet is visible. The reason of this is supposed to be in the difference in the rates of vibrations of the molecules of the metal. As the heat increased, the vibrations became more rapid, and the waves smaller and smaller, at length becoming visible, and gradually giving rise to all the colours of the spectrum.

Again, it is found that *every substance*, when in a state of vapour, and glowing with intensity of heat, *shines with certain tints only*. This light, when analysed by the spectroscope, gives a spectrum of coloured lines or bands *occupying definite positions*, with dark spaces intervening. The spectrum also varies with the heat of the vapour, and also with the pressure. Here, then, we have a means of distinguishing a glowing solid or liquid body from a glowing gas or vapour, and the spectrum of one glowing gas or vapour from that of another. Thus, if a glowing substance gives a spectrum consisting of bright lines or bands, we know the substance must be gaseous. If certain bands of the spectrum are much brighter than the rest a portion of the source of light is certainly gaseous; or, if the spectrum is continuous, and shows no bands much brighter than the rest, the source of light is within a solid or liquid body, or a gaseous body at say high temperature and pressure. Hence, if there is sufficient and independent reason for supposing the source of light not to be at a very high pressure, we may safely infer that the substance is either liquid or solid, and so on.

We also have the means of ascertaining the composition of the substance which is the source of light, by comparing the spectrum with the known spectrum of different substances. Thus, if the bright lines of an observed spectrum occupy exactly the same position as the bright lines of any known vapour, we may feel certain that the source of the spectrum is the same as this vapour.

Again, it has been found that a vapour has the power of absorbing the same tints as it unites. Thus, if through a mass of glowing vapour a mass of solid or liquid is shining, and the spectrum of both examined, it will be noticed that the spectrum from the solid or liquid is crossed by dark or bright lines which correspond to the tints of the vapour. Sir D. Brewster, in dealing with this part of the subject, found that when sunlight is transmitted through the thick vapours of nitrous acid, a number of new dark lines are seen. He found that when light, giving a continuous spectrum, is transmitted through the gas instead of sunlight, these lines are visible. He also found that by increasing the heat of nitrous acid, the lines became stronger, and new lines also appeared. By following on this investigation, Kirchhoff and Bunsen, after many experiments, came to the conclusion that the dark lines in the solar spectrum were due to absorption, and were thus enabled to announce the following general law: "Every substance which emits at a given temperature rays of certain orders of refrangibility, possesses the power at that same temperature of absorbing rays of those same orders of refrangibility."

Summing up the main results obtained on examining the spectra from different sources of light, we find—

1. *Solid and liquid bodies in a state of incandescence give out continuous spectra.*

2. *That glowing vapours and gases give out spectra with bright lines on a dark background, these lines between given limits of temperature and pressure being different for different substances.*

3. *When the light from any luminous body is caused to pass through a gas, such rays are absorbed by the gas as it would itself emit when rendered incandescent, the temperature and pressure being the same.*

Further, we may add that some vapours (and probably all) at a very high temperature and pressure give continuous spectra, and probably glowing vapours at very high temperature and pressure, shining through cooler absorbent vapours, give the same spectrum as incandescent solid or liquid bodies shining through the same vapours.

211. Constitution of the Sun.—It is from the three results just mentioned that the constitution of the sun and other heavenly bodies has been obtained. Thus the vapour of silver, when incandescent and passing through a prism, gives a beautiful green line across the spectrum. Sodium gives one bright yellow bar in exactly the same position of the dark Fraunhofer line which is in the yellow of the spectrum, the remainder of the spectrum being rendered dark by the primary colours being absorbed. As above stated, each substance has its own characteristic line, or group of lines; and even if it be a compound substance, each constituent will reveal its own line or lines, each in its own position—it being remarkable that these lines never interfere with each other in taking their position in the spectrum.

The test for the presence of sodium is so delicate that the three millionth part of a milligram (about the two hundred millionth part of a grain) of a salt of sodium will colour the flame yellow and give the sodium line in the spectrum. On allowing an intense light—for instance, the oxy-hydrogen lime-light—to send a ray through a prism, a spectrum is obtained containing no dark line; but on allowing this light to fall through a flame coloured by sodium chloride (common salt) the Fraunhofer line appears in the centre of the yellow. From this we draw the result (3) that the sodium flame has the property of absorbing the rays of the same colour which it sends out (yellow), and also that incandescent vapours and gases absorb the rays of the same colour which they emit. The light from the sun always shows these dark lines. Hence it is inferred that the light before reaching us must have passed through the vapour of sodium, which must exist either in our atmosphere or in that of the sun; and in like manner when we find that in the solar spectrum there are dark lines occupying the places of the bright lines belonging to particular metals, we come to the conclusion that the sun is surrounded by a gaseous atmosphere which contains these metals in an incandescent state.

The lines in the sun's spectrum, as previously mentioned, furnishes information respecting the different *temperatures* of the substances under examination. Thus the dark lines indicate the presence of vapours around the sun which are cooler than the sun's mass. If bright lines are observed they indicate the presence of vapours hotter than the general mass. Again, vapours may exist of whose presence no spectroscope evidence can be obtained, simply because the temperature of the vapour is at the same temperature as the general mass of the sun.

In this way it has been proved that the sun's atmosphere contains, amongst others, the following metals in a state of vapour: aluminum, sodium, iron, magnesium, cobalt, calcium, chromium, barium, copper, nickel, manganese, titanium, zinc, and also glowing hydrogen in great quantities, the lines of the latter element being occasionally seen bright when certain parts of the sun are examined, showing, at such times, that the hydrogen there is hotter than the surface underneath it. Again, according to Dr. Draper, the bright lines of oxygen, and probably those of nitrogen, are present in the solar spectrum; thus proving the presence of oxygen, and probably that of nitrogen in the sun's atmosphere, but are hotter than the glowing surface, above which they are situate.

And, further, studying the vapours in this manner, it seems very probable that the sun contains all the terrestrial elements, and possibly in proportions not differing very greatly from those that prevail in our own earth.

The particular part of the sun's atmosphere containing the incandescent metallic vapours appear to be a comparatively narrow band, extending not very far above the atmosphere. This has been called the **reversing layer**, as here the portions of the sun's light appear reversed and the Fraunhofer lines produced.

212. Sun's Condition.—Kirchhoff, in his speculations concerning the *sun's condition*, supposes that body "to consist of a solid or partially liquid nucleus in a state of intense heat, emitting, therefore, rays of all orders of refrangibility. Around this nucleus is an exceedingly complex atmosphere of comparatively low temperature, containing the vapours of many of the elements forming the sun's body. The rays of light emitted by the nucleus are partially absorbed by the vapours in the sun's atmosphere, each vapour absorbing rays such as it emits at the same temperature, and so causing dark lines agreeing in position with the bright lines of its spectrum as a glowing gas."*

No doubt the greater part of Kirchhoff's theory is true, but it is not by any means certain that the great mass of the sun consists of solid or liquid matter. Indeed, from our present knowledge of the sun, his small density as compared with the earth's, namely, less than one-fourth, and the mobility of his visible parts to a great depth, where the pressure must be enormous, there seems reason for believing that all the light forming the continuous background of the solar spectrum comes from gaseous matter at great pressure.

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* Proctor. Spectroscope, p. 63.

213. Chromosphere, &c.—During total eclipses of the sun red protuberances, appearing in the shape of huge red flames, have been observed to appear to shoot from beneath the edge of the moon's disc to the height of eighty and even one hundred thousand miles. They were for many years supposed to belong to the moon, namely from 1706 to 1842, when that notion had rather a rough shaking by the total eclipse visible in France and Italy, observed by many scientific men; and in the year 1860 these flames themselves, by the aid of Mr. De La Rue and artistic photography, told their own tale on his photographic plates, announcing themselves as belonging to the sun, and, more than this, giving us information regarding their extent (one of the prominences registered extended 72,000 miles from the sun's surface into his atmosphere), and also what they must consist of. The exact position and extent of these prominences was recorded by photographs *taken during the progress of the eclipse*, and they were found to change so rapidly and remarkably as clearly to indicate that they consisted of *luminous vapours*.

According to J. N. Lockyer, these red flames are local aggregations of an envelope *(chromosphere sierra)*, chiefly consisting of hydrogen, which extends over the whole of the solar sphere to an average thickness of about 5,000 miles. They undergo continual and often most rapid changes. For instance, Mr. Lockyer saw an outburst 27,000 miles high, which *disappeared entirely in less than ten minutes;* and far exceeding this is one described by Professor Zöller, which shot up as a tongue of flame 50,000 miles high, and he says he could scarcely believe his own eyes when he saw a sort of flickering motion in this flame, caused by the *travelling of a flame-wave from its base to its point in the course of two or three seconds.* At another time an immense cloud-like mass of incandescent hydrogen was seen resting on the top of a conical prominence. In a few hours afterwards this mass, greatly increased in size, was seen floating many thousands of miles above the prominence. It is believed that these extraordinary phenomena are, in a great measure, due to local variations of temperature similar to those which produce storms, cyclones, &c., in our own atmosphere; but the differences of temperature that cause the solar storms cannot be less (as Kirchhoff remarked) than thousands of degrees.

214. The **Spectroscope also shows us what the spots on the sun's surface really are,** namely, parts of the solar atmosphere in which the temperature of the glowing gases has undergone reduction, and that they appear to us black simply because they are less bright than the surrounding portions of the photosphere. The darkened area of the sun spot is an area of a powerful absorption, produced by the *density* of the metallic vapours being *increased*, arising from a cooling of these vapours, which will produce a *downward* current drawing them nearer to the sun's surface. Those bright stripes termed *faculæ* are just the reverse, depending on their higher temperature, and producing a current in the opposite direction, viz., *upwards*.

Still, more than this, the spectroscope has been applied to find the **velocity** with which the various vapours move about in that atmosphere. Mr. Lockyer by the aid of this instrument determined the *velocity* of the rush of those currents of white-hot hydrogen. Thus, viewing the sun's surface through his spectroscope, he saw the Fraunhofer line F (hydrogen line) appeared bent, sometimes by shifting at several points towards the *red* end of the spectrum, and at other times by a displacement towards the *violet* end. Now, the shiftings and movements of this line indicate alterations in its *wave-length*, which diminish as the line moves towards the *violet* end and increase as it moves towards the *red* end. The displacement discerned was to the extent of *one ten-millionth* of a millimetre, showing that the incandescent hydrogen is rushing at the rate of 38 miles per second, which equals 136,800 miles per hour—in the first case *towards* the observer, but in the second case *from* him. Now, these motions on the sun's surface must be upwards in the first case and downwards in the latter case, if the *central part* of its disc is under observation, as no movement *along* its surface will alter the distance of the moving body from the eye of the observer. But in viewing the *limb** of the sun a motion of approach *to*, or recession *from*, the eye of the observer will be one *parallel to*, or *along*, the sun's surface. These movements betoken storms which rage on the surface of the sun. Thus, supposing a *cyclone* raging over a portion of the sun's disc, which we are viewing *edgeways*, it is evident that the current will be *towards* us on one side and *from* us on the other. This will show itself in the direction of the F (hydrogen) line on the *violet* end of the spectrum on one side and towards the *red* end on the other. This reflection has been witnessed repeatedly. The lateral displacement of this line on one occasion was such that it made it appear treble. A portion of the hydrogen flame had *no* motion towards the observer, while others were approaching him at velocities increasing to the rate of 120 miles per second, or 432,000 miles per hour. To comprehend the terrific violence of these storms of incandescent hydrogen we must remember that the greatest speed of the most violent hurricanes which occur on our globe is 100 miles an hour. (See 114.) Then what must be the storm which rages at the rate of 432,000 miles in the same time, or 431,900 miles more per hour? The interior of each of these whirlwinds of flame is the *spot*.

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* Border.

These spots have been shown to have a *cycle* of increase and diminution extending over a period of nearly *eleven* years, known as the sun-spot period. It has also been ascertained from facts collected by Mr. Meldrum, the astronomer at Mauritius, that the periodical *maxima* of these spots are those of the most numerous and violent hurricanes on our own globe, thereby leading us to suppose that our atmosphere is in some way connected with that of the sun. Further than this, evidence has been obtained by the spectroscope, which suggests the existence of a very attenuated atmosphere between the sun and the earth, as bright bands, one of which seems identical with the third line of the *corona*,* have been observed in the spectra of the aurora of the zodiacal light, and even the phosphorescent glow seen at times over the general surface of the sky on a starlight night.

215. Spectra of the Stars, &c.—We have already mentioned that the stars give spectra resembling in general features the spectrum of the sun, but differing in special details. (See 207.) Hence we conclude the stars resemble our sun in being masses glowing with intense heat, the spectrum of their light being continuous. Around these masses there are envelopes of vapour relatively cool, which absorb certain portions of the light from the glowing matter within, thus causing the stellar spectrum to be crossed by dark lines. We have also mentioned how astronomers, by the differences in the spectra of the stars, have been able to divide them into four classes. We here give a few more facts respecting them.

In the first class the four lines of hydrogen are remarkably strong. Besides these lines there can be seen five black lines in the yellow belonging to the sodium, the chief magnesium lines, and probably some lines of iron. To this order belong Sirius, Vega, Altair, Regulus, Rigel, the leading stars in Ophinchus, and of the Great Bear, &c. These stars are no doubt much hotter than our sun. The second class is that of the yellow stars, as Capella, Pollux, Aldebaran, Arcturus, Alpha of the Great Bear, Procyon, &c., the spectra of which correspond with those of the solar spectrum. It may be mentioned that all the stars classed under this type have not the same spectrum, some being intermediate between the first and second types—Procyon, for example—and some intermediate between the second and third, as Aldebaran.

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* (See 184.) The extent of this is such that distinct indications of its photographic action have been obtained at a distance of nearly two million miles from the surface of the sun. The inner part gives three bright lines on a faint continuous spectrum—two showing the presence of incandescent hydrogen, the third indicating some other substance.

In the third order are included Betelgeux, Antares (α Scorpii), Scheal (β Pegasi), α Herculis, and others, mostly of red or orange.

The spectrum consists of a double system of nebulous bands and dark lines, the principal lines of the second order being seen, with the exception of the hydrogen lines, which in some cases are not distinguishable at all, and in others very faintly. Secchi, from the spectrum of this class resembling that of a sun-spot, infers that these stars have spots on them like our sun, but relatively much larger. This opinion is to some extent confirmed by the fact that among the stars of this type are some of the most remarkable *variable* stars. Thus, for instance, Betelgeux is a noted irregular variable; Scheal and α Herculis are both variable; and to this order also belongs the remarkable ο Ceti, sometimes called *Mira*, which shines as a second magnitude star for a fortnight at intervals of 330 days, taking three months in waxing from invisibility to its full magnitude, and the same time in waning. It is therefore inferred that these stars are variable in consequence of large spots on their surface similar to our sun.

The fourth class consists of small red stars, the spectrum of which consists of three bright bands separated by intervening dark spaces.

216. Colour of Certain Double Stars.—To explain this phenomenon spectroscopic analysis has also been employed. Thus in the case of the double star, Albireo, one orange, the other blue. Both spectra show the complete range of the spectral colours, and we hence learn that the inherent light of both stars is white, but the spectrum of the former showed several strong lines in the green, blue, and violet portions, and no lines in the orange part, thus showing an excess of orange light, so that the star shines with an orange tint. In the spectrum of the blue one there are several strong bands in the orange and yellow parts, and very few lines elsewhere, thereby showing an excess of blue and violet light, causing the star to show a well-marked blue colour.

217. Measuring Motions of Recession and Approach.—Another use to which spectroscopic analysis has been applied is the measuring rapid motions of recession from or approach towards the observer. We have already shown how the velocity with which the various vapours move in the sun's atmosphere is measured; in a similar manner the motion of stars may be determined. To explain this more fully we must remember that light travels in a series of waves, which advance in all directions from the source of light, the wave motion being thus transmitted. Now, the different refrangibility of light of different colours depends on the differences of the light-waves in length—or, which amounts to the same thing, upon the differences in the rate of vibration. Thus, the waves producing red light vibrate less quickly than those producing orange, those producing orange less quickly than those producing yellow, and so on, the waves producing violet light vibrating most quickly of all. Then, since the colour of light depends on the number of vibrations which reach the eye in any given time, it follows that if the eye be *approaching* the source of light, so as to receive more vibrations from light of any given colour than it could have received if stationary, the colour of that light will be altered to a colour corresponding to a part of the spectrum nearer the violet, and *vice versa* if the eye be *receding* from the light, so as to receive fewer vibrations than it otherwise would, the colour of the light will be altered so as to correspond to a part of the spectrum nearer to the red.

Huggins, in applying this reasoning in the case of Sirius, first satisfied himself that the dark line F in the spectrum really corresponded with the F line of hydrogen. He then carefully examined the position of this line in the spectrum of the star, and found it displaced towards the red, thereby indicating that the star was receding from the earth. The amount of observed displacement indicated a velocity of 41½ miles per second. But as the earth moved in its orbit during that time about 12 miles, the real recessional motion was 29½ miles per second. The sun himself is in motion towards the constellation Hercules, but the rate of this motion is uncertain. According to Struve it is a little more than three miles per second, though Mr. Proctor thinks it is more. At any rate it is certain that the distance between Sirius and the sun is increasing at the rate of nearly thirty miles per second. In like manner it has been ascertained that Betelgeux, Rigel, Castor, Regulus, and other stars, including five belonging to the Great Bear, are receding from the sun at rates varying from seventeen to thirty miles per second; while others, including Arcturus, Vega, *α* Cygni, Pollux, and *α* Ursæ Majoris, are approaching the sun at a still greater rate.

218. Nebulæ.—Not only has the spectrum analysis been applied to the solar system, but it has been extended far beyond, adducing, in the hands of Dr. Huggins and others, evidence regarding the present conditions of *non-terrestrial matter*, and throwing much light on what is termed the *nebular hypothesis*. *Nebulæ* is the name given to the system of stars which appear as little clouds of self-luminous matter of very little density, being in a highly gaseous state. These are scattered in all directions in the remote heavens.

The nebulæ (of which nearly four thousand are known) are of two classes, some appearing, by the aid of powerful telescopes, *as immense clusters of stars*, termed resolvable, while others appear, even by the aid of these telescopes, luminous mists or gases, and are termed irresolvable. In the first class the spectra exhibited are similar to the sun and the other planets, and in the spectra of the latter class are found three bright lines—one of hydrogen, one of nitrogen, and the third is yet undetermined.

Now, if this latter class had been a cluster of stars its spectrum would have been *continuous*, like that of a single star, though extremely faint. Hence Dr. Huggins concluded that the spectrum was not formed like that of the sun or stars, by light proceeding from a white-hot nucleus enveloped in an atmosphere whose absorptive power converts its bright lines into dark ones, but *by luminous matter in a gaseous condition*. Dr. Huggins examined, one nebula after another, and found that they might all be distinctly separated into two groups—those giving a spectrum consisting of three bright lines, which are *gaseous*, and those giving a continuous spectrum, which are therefore *stellar*. Regarding the chemical constitution, two out of the three lines are characteristic of hydrogen and nitrogen.

Although the nebulæ appear to be very different from stars, it is possible that there is a close connection between them, as suggested in the nebular hypothesis. Sir W. Thomson and Professor Tait are inclined to believe that true nebulæ are of the same nature as comets, and that, instead of consisting of glowing gas, they consist really of clouds of stones "clashing together," or "banging about," in an atmosphere of hydrogen, and that the heat thereby evolved is sufficient to give rise to the luminous appearance. Even Mr. Lockyer is inclined to favour this latter view, and experiments made by him seem to show that a connection between nebulæ, meteorites, and comets is highly probable.

In concluding the present notice of the spectrum analysis, we cannot do better than give a summary of the facts elicited by Dr. Huggins's investigations in his own words :—

(1) "All the bright stars at least have a structure analogous to that of the sun."

(2) "The stars contain material elements common to the sun and earth."

(3) "The colours of the stars have their origin in the chemical constitution of the atmosphere which surrounds them."

(4) "The changes in brightness of some of the variable stars are attended with changes in the lines of absorption of the spectra."

(5) "The phenomena of the star in Corona appear to show that, in this subject at least, great physical changes are in operation."

(6) "There exists in the heavens true nebulæ. The objects consist of luminous gas."

(7) "The material of comets is very similar to the matter of the gaseous nebulæ, and may be identical with it."

(8) "The bright points of the star-clusters may not be in all cases stars of the same order as the separate bright stars."

TERRESTRIAL MAGNETISM.

219. Aurora Borealis.—Before concluding we will just offer a few more remarks respecting the connection between the auroral displays and magnetism. The direction of the dipping needle gives us the direction of a line of force, or the direction in which a magnetised particle would tend to move, and we find that the lines of force start from near the poles and rise to a great height above the surface of the earth near the equator. Now, the rays which are seen in the aurora are always parallel to the dipping needle—that is, parallel to the magnetic lines of force; hence we naturally infer that electricity—or magnetism, which is the same—is in some way or another the agent in auroral displays.

When the light of the aurora is examined by the spectroscope it is found to give a spectrum of one bright line, in the yellow green, a spectrum which is totally different from that of oxygen or nitrogen, the gases of the atmosphere. A red line is also frequently in the spectrum of the aurora, and its brightness seems to vary in an inverse ratio of that of the green line. Besides these two principal lines some faint ones may generally be seen, which appear to coincide with those which are seen in the spectrum of rarified atmospheric air. The variability which is seen in the spectrum leads us to the conclusion that the light must either come from different sources or is produced under varying conditions. Now, many substances are known during the process of decomposition to give out a peculiar spectrum—that is, when the elements of which they are composed are passing from an old combination to a new one. This has been thought by some to furnish the key to the explanation of the peculiar spectrum of the aurora. Thus, if, which is very probable, the electric discharge takes place between particles of ice and water, there will be a decomposition going on at the surface of these particles, just in the same manner as water may be decomposed into its component parts by passing through it a current of electricity from a galvanic battery.

M. Planté,[*] by experiments in which he studies the behaviour of the electric discharge from a powerful battery in the presence of aqueous masses, produced a series of phenomena presenting a most complete analogy to the polar lights; and from these he comes to the conclusion that in the aurora the imperfect vacuum of the upper regions of the atmosphere forms a vast conducting envelope, the light being caused by positive electricity flowing off from the earth, through the icy mists or clouds which float above the poles, towards the planetary spaces.

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[*] "Comptes Rendus," vol. lxxxiii.

It is very probable that light and magnetic disturbances are transmitted by the same medium, and that there is some kind of electric communication between planet and planet. This latter fact is corroborated by the close relation which has been shown to exist between the terrestrial magnetic storms and the prevalence of sun spots.

220. Instruments used in Magnetic Observations.—In the former part of this work we treated at some length on the subject of Terrestrial Magnetism and Electricity. We have also shown, when treating of the influence of the sun on the earth, that the maximum sun spot period coincides with a period of magnetic storms and brilliant auroræ, so that now we have only to describe the instruments by which the distribution and intensity of magnetism has been determined.

Among the instruments used in magnetic observations the chief are, the declinometer, the bifilar, or horizontal force magnetometer, and the balanced or vertical force magnetometer. The **Declinometer** consists of a bar-magnet, freely suspended by a bundle of untwisted silk fibres. The variations of the positions of this magnet correspond with those in the vertical plane in which the earth's force is exerted. The **Bifilar** is a similar bar-magnet to the above, suspended by two nearly parallel bundles of fibre, slightly separated. The double point of suspension is twisted round until the bar is in a position *perpendicular* to the magnetic meridian. It is then kept in this position by two equal forces acting in opposition, namely, the gravity of the bar and its appendages, which tend to untwist the skeins upon which it is suspended, and the horizontal component of the earth's force, tending with an equal force to turn the bar in the opposite direction. Now, the former force always remains constant, hence any variations of the latter force will produce corresponding variations in the position of the magnet, so that by observing these variations or changes of position, the variations of the horizontal magnetic force are determined.

The third of these instruments—the **Balanced Magnetometer**—is a bar-magnet, very delicately poised on knife edges, so that it can move in a vertical plane, something similar to the beam of a balance. It is placed at an angle of 90 degrees (right angle) to the magnetic meridian, being kept in a horizontal position by a weight, which counteracts the tendency of the earth's vertical force to place it in a vertical position. Now, as this is constant, it is evident that any changes in the amount of the vertical force would be shown by corresponding changes in the magnet's position.

221. The indications of these instruments were formerly observed by viewing the divisions of a fixed scale reflected by a plane mirror attached to each of the magnets, through a telescope, which required observations to be taken at least every two hours, night and day, to furnish us with anything like a correct register of these variations. Hence the necessity of some other mode of registration—the best of which must evidently be the one that will cause it to register its own changes. This has been accomplished by the aid of *photography*, so that we have now an uninterrupted and faithful record of these magnetic changes at the Royal Observatory, Greenwich. The mean elements for this year (1885) are mean declination, or variation of the compass, 18° 15½′ W.; inclination, or dip, 67° 31′; intensity, or mean horizontal force (in British units), 3·9. The true or astronomical north can be found from the magnetic thus: Take the compass on a level surface, and turn the card round until the marked end of the needle points 18° 15′ towards the west; then the zero point of the card will be in the direction of the true or astronomical north, while the needle itself will be pointing to the magnetic north.

The method of photographic registration is thus: A concave metallic mirror, 3 inches in diameter, is attached to each of the three magnets by a frame possessing all requisite adjustments, &c. The rays of light from a gas-burner, which is placed about 2 feet from the mirror, pass through a small aperture in a metallic plate, and fall on the mirror, from which they are reflected to a focus about 9 feet distant. As the source of light is fixed, the movements of the focal point of light will correspond with the movements of the magnet. A cylinder, covered with prepared photographic paper, is placed so that the point of light may fall on it, the axis of the cylinder being parallel to the focal point's motion. This cylinder is continually being turned round on its axis by clock-work, and by the movements of the point of light and of the cylinder combined the magnetic curve is traced on sensitive paper.

THE NEBULAR HYPOTHESIS; OR, THE ORIGIN OF THE EARTH.

[A paper read by the author, which was published in the *London University Magazine*, 1879.]

It may be inferred from the title of the present paper that *how* and *when* the earth was formed is now definitely known. We may reply, "Not yet," but perhaps at some future date science may be able to reveal the fact. Every day we seem to obtain some additional truths regarding our own and the other planets; science now proving the "identity of the constituents of the earth with those of the heavenly bodies." The object of this paper is to state in simple language how this knowledge has been obtained, and the conclusions that have been drawn therefrom.

The science of chemistry has shown that this earth is composed of sixty-five elements or elementary substances, and of these, only about seventeen occur extensively, namely, oxygen, hydrogen, carbon, sulphur, silicon, boron, aluminum, chlorine, calcium, magnesium, iron, sodium, potassium, fluorine, lithium, and manganese; these, combined in various ways, compose the greater part of the earth and its fluid envelope; the others are of so rare occurrence as to be interesting only from a chemical point of view.

Of these seventeen elements, several have been proved to exist in the *sun*, the centre of our universe, *i.e.*, the solar system. This knowledge has been derived from the aid of the *spectroscope*—an instrument used for the purpose of analysing the rays of light from any luminous source. It consists of a series of prisms of flint glass, which cause the rays to be dispersed, and which thereby reveal the chemical elements of a body by the character of its spectrum, when reduced to a state of glowing vapour.

A beam of light in passing through a prism is broken up into its constituent parts; thus a sunbeam admitted through a crack in the shutter in a dark room, forms a straight line, and causes an image to appear on the floor; but, on the beam passing through a horizontal prism, the rays are refracted, and form on the wall or screen seven beams of colour, namely, beginning at the lowest, red, orange, yellow, green, blue, indigo, and violet; this is what is termed the *solar spectrum*, and the seven colours are the constituents of white light. Supposing, instead of white light, we use a coloured one, for instance, such as that emitted by burning sodium; the colour of the spectrum is yellow, or the same as the light emitted by the sodium; but, if a beam of white light is made to pass through this yellow light, there appears a spectrum consisting of seven colours as before, and in precisely the place of the yellow sodium spectra appears a dark band. Or, again, if the vapour of silver, when incandescent, passes through a prism, it gives a beautiful green line across the spectrum; and in a similar manner, if a beam of white or solar light is made to pass through, there appear the seven colours, and a dark line in exactly the place of the green one; hence it appears that the burning sodium and silver each absorbs the same rays as it emits, and only its own less luminous rays fall upon that part of the spectrum appearing as dark bands. Examining the spectra in this way from different sources of light, the following main results are obtained :—

(1) *Liquid and solid bodies, in a state of incandescence, give out continuous spectra.*

(2) *Glowing vapours and gases give out spectra with bright lines on a dark background, and these lines are different for different substances.*

(3) *When the light from any luminous body is caused to pass through a gas, such rays are absorbed by the gas as it would itself emit when rendered incandescent.*

So we see each substance has its own characteristic line, or groups of lines; even if the substance is a compound, each constituent will reveal its own peculiar line or lines, and thereby, by minutely examining the spectrum, the elements may be ascertained.

It is by means of this "spectrum analysis" that the composition of the sun and other heavenly bodies has been obtained. Thus, suppose the spectroscope arranged so that the light from a sodium flame might pass through the lower part of a slit, and a sunbeam through the upper part, and compare their spectra; then introduce in succession the flames of hydrogen, iron, copper, &c., and if we find that in the solar spectrum there are dark lines occupying the bright lines of these particular metals, we come to the conclusion that the sun is surrounded by a gaseous envelope or atmosphere which contains these metals in an incandescent state, and, continuing in this manner, it has been proved that the sun's atmosphere contains, amongst others, the following metals in a state of vapour: sodium, iron, nickel, aluminum, zinc, cobalt, magnesium, copper, barium, chromium, calcium, and immense quantities of glowing hydrogen.

By continuing this investigation further, it has been found that the constitution, not only of the sun, but nearly, if not all, of the heavenly bodies, agree in many particulars with that of this earth.

It has even been applied to the systems of stars, called *Nebular*, which appear as little clouds of self-luminous matter, of very little density, being in a highly gaseous state, and scattered in all directions in the remote heavens, the result of which is, that one class exhibit spectra similar to the sun and planets, and the other a spectrum containing three bright lines: one of hydrogen, one of nitrogen, and the third as yet undetermined. This class are termed *irresolvable*, as they always appear, even by the aid of powerful telescopes, luminous mists or gases; the other class are termed resolvable, because they appear as immense clusters of stars.

From these results the conclusion has been arrived at that the sun and other members of the solar system are similar in composition, and this is a great link towards proving that they have all been derived from the same source, but in what manner we can at present only conjecture.

Several theories have been put forth accounting for the origin of this earth, the chief of which is the "Nebular Theory," by means of which Laplace, the great French mathematician, attempted to trace the formation and growth of the sidereal bodies from one great rotating mass of matter.

It has been proved by the spectroscope that some of the nebulæ are *gaseous* and others *stellar ;* that is, some are still so hot as to be in a state of vapour, but others have so far cooled as to become stars ; indeed, we find different forms of nebulæ illustrating different stages in the process of condension. Thus, in one stage there is simply a cloud-like mass ; in another, it has assumed a spiral form—a fine example, for instance, to be seen in *Canes Venatici*, showing that there is a rotary motion among the molecules of which it is composed ; in another, we have a globular form, surrounded by a ring ready to break up and form other stars or planets, presenting the exact appearance of Saturn when its ring is seen through a telescope edgewise. As the condensation of the nebulæ proceeds it becomes more and more rapid, the temperature rapidly rises, and, after a time, an intensely heated incandescent nucleus is formed and the nebulæ becomes a star. Further, it has been ascertained that the stars differ in temperature, some are hotter than the sun, others much cooler. Thus, when condensed from nebulæ to a sun their temperature is exceedingly great, but after a time, when continued condensation reduces to a fluid state, the process of cooling commences.

The "Nebular Hypothesis" is that, at first, the whole solar system existed in a state of vapour only, similar to the gaseous nebulæ which still exist ; and that all sidereal bodies are continually growing, and other bodies forming from the aggregation of nebulous matter.

Laplace, in attempting to trace from physical laws the operation of this development, showed that a mass of gaseous or fluid matter, when made to rotate rapidly, would spread out in the plane of rotation and become a thin disc, becoming wider and thinner as the velocity of rotation increased, until the centrifugal force overcomes the attraction of cohesion, when whole rings, or parts of the edge, would fly off, and contract by gravitation into masses of a spheroidal shape, and still continuing to revolve round the centre from which they become detached. In these detached masses, the velocity of the outer edge would greatly exceed that of the inner edge, and this excess on one side would give the newly-formed planet a rotation on its axis. This process repeated again and again, with the same stratum, would form the successive spheroids, each revolving in a narrower orbit, until the entire nebula was replaced by the system of planetary bodies.

Again, these planets, as they were formed, might, in their earliest stages, throw off *their* outer edges, or fragments, forming moons or satellites revolving round the planet as their centre.

This is in all probability the manner in which our earth had its origin. An immensely-heated vaporous matter extended for hundreds of millions of miles, and, revolving on its axis, the outer edge would travel at such a speed that our comprehensions cannot grasp. Then, think what its centrifugal force must have been, and this would evidently be greatest at the equator. Hence the matter would be more likely to fly off from these regions, where it would at first form a belt or ring similar to what still exists round the planet Saturn. Afterwards, probably breaking its continuity, the particles would fly together, forming a planet, which would revolve around the original central mass. And as the nebular continued to condense, planet after planet would be formed, the central mass, or what is left of it, remaining an intensely-heated body, consisting of a more or less dense nucleus, surrounded by an envelope of vapour composed of elements many of which can only exist in that form under the influence of extremely great heat. This remaining central part of the nebular is the *sun*, which is, in all probability, still continuing this process, and must eventually become a solid globe; though, according to calculations made by eminent philosophers, if the sun is feeding itself, a diminution of one-thousandth of the sun's diameter would produce heat enough to suffice for its entire radiation during 21,000 years.

This theory accounts for many of the phenomena of the solar system ; it enables us to see the reason they all revolve round their common centre, the *sun ;* the reason they spin upon their own axis in the same direction ; and how it is that the remotest planets, formed of the most volatile and rapidly-moving matter, are also the largest and least dense, while the heaviest and smallest are near the centre.

Our earth itself gives us plenty of evidence tending to confirm the theory of its once being in a molten state ; one of the principal facts being its spheroidal shape, as it must have been in a fluid state to have bulged out at its equatorial regions whilst rotating on its axis. Active volcanoes point to the existence, at some unknown depth, of enormous masses of matter in an intensely heated state, and even in a state of fusion as lava. We have also very strong evidence on chemical grounds that the earth must have been very much hotter than it is now, as many of the compounds of which the earth is composed would require very high temperatures for their formation.

We will now bring this paper to a close, having briefly stated the most general accepted theory of the origin of this earth. It may take years to fully establish this theory and the proof of it; but still we feel certain it is only a matter of time.

SYLLABUS OF PHYSIOGRAPHY ISSUED BY THE SCIENCE AND ART DEPARTMENT.

FIRST STAGE, OR ELEMENTARY COURSE.

The candidate will be expected to have a knowledge of ordinary Descriptive and Physical Geography—so far as required by the Fifth and Sixth Standards of the New Code, and of the specific special subjects of secular instruction—Principles of Mechanics, and Physical Geography.

Questions may be set in these subjects:—

The parts played by gravitation, cohesion, and chemical affinity in producing chemical and physical differences in matter.

Elementary ideas of the various conditions of matter as regards energy, embracing heated states and electric and magnetic states.

Elementary notions of chemical action. The formation of binary compounds.

Breaking up of compound matter into simpler forms. The chemical elements.

WATER.—Its composition and several states.

CHEMICAL AND PHYSICAL CHARACTER OF THE CRUST OF THE EARTH.—Rocks, stratified and unstratified. Inorganic Materials (the more frequent simple minerals formed of them): Granite, volcanic products (ancient and modern), sedimentary rocks, conglomerate sandstone, shale: limestone gneiss, slate, marble, sand, mud, and surface soil. Materials partly produced by organisms: Coal, peat, chalk, coral, and limestone. Bodies of which these are compounds. The chemical elements of which the crust is chiefly composed. Observations indicating an increased temperature in the interior of the earth. Volcanic Phenomena, and distribution of volcanoes. Earthquakes and slow upheavals and subsidences of the earth's crust.

THE SEA.—Salts dissolved in sea water. Depth and form of sea bottom. Remarkable inequalities. The chief currents. Distribution of temperature and density. Phenomena of Arctic and antarctic regions, floes, pack ice, icebergs, &c. Action of the sea on the earth's crust. Influence of the sea on the distribution of climate.

THE ATMOSPHERE.—Height and composition. Atmospheric pressure. Use of the barometer. Distribution of temperature, horizontal and vertical. Use of the thermometer. Evaporation and condensation. Aqueous vapour, rainfall, ice, snow. Region of extreme dryness and of great rainfalls. The prevailing air currents. Cyclones. General conditions of climate.

Action of rain, springs, rivers, and glaciers upon the earth's crust.

General ideas of the changes which the earth's surface has undergone in the past, and of evidence as to succession of various forms of life.

Elementary notions as to the effects of terrestrial electricity and magnetism; thunderstorms; aurora; the mariner's compass.

EXAMINATION PAPERS.

PHYSIOGRAPHY. (1877).

Examiners.—J. Norman Lockyer, Esq., F.R.S., and John W. Judd, Esq.

FIRST STAGE, OR ELEMENTARY EXAMINATION.

Instructions.

You are permitted to attempt only eight questions.

The first four questions must be attempted by you, and you are then at liberty to select four others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers in brackets.

51. What are deltas? How are deltas formed? Name six of the largest deltas in the world. [See 94.] (15)

52. Why does rain fall in such great abundance in the west of Ireland? What is meant by the statement that the mean annual rainfall of a place is 70 inches? What becomes of the water which falls upon the earth in the form of rain? [See 125 and 92.] (15)

53. What is meant by the snow-line? Why is the snow-line sometimes higher on one side of a mountain chain than on the other? Why do glaciers descend below the snow-line? [See 128.] (15)

54. What is a volcano? Name the active volcanoes of Europe, and state in what parts of the same continent *extinct* volcanoes occur. [See 55—57.] (15)

55. State, in the order of their relative abundance, the eight chemical elements which enter most largely into the composition of rocks. [See 45.] (10)

56. What is the difference in composition between peat and coal? By what changes would the former pass into the latter? [See 49.] (10)

57. Of what materials are clay, shale, and slate chiefly composed, and in what respects do these rocks differ from one another? [See 49.] (10)

58. What is the principal work performed by rivers in modifying the features of the earth's surface? Explain the mode of origin of the winding curves in which rivers so frequently flow. [See 94.] (10)

59. Draw a sketch map of the Atlantic Ocean, and indicate upon it the courses of the chief of the great currents. [See Maps and 86.] (10)

60. What are the differences between continental and insular climates, and how are these differences caused? [See 134.] (10)

61. In what direction does a magnetic needle in this country point, and why does it not everywhere assume a due north and south direction? [See 33 and 34.] (10)

62. Why are coral reefs limited to certain restricted areas of the earth's surface? [64.] (10)

SECOND STAGE OR ADVANCED EXAMINATION.

Instructions.

You are permitted to attempt only six of the following questions, and the three which stand first on the paper must be included among these.

The value attached to each question is indicated by the number in brackets.

71. A steamer crosses the Pacific from Vancouver's Island to Otago. State the nature and direction of the great permanent air currents which she may be expected to encounter at different points during the voyage, and explain the causes to which each is due. [See Maps, and 104—107.] (18)

72. Explain the precession of the equinoxes. [See 167.] (19)

73. How has the chemical composition of the solar atmosphere been determined, and how can we measure the velocity with which the various vapours move in that atmosphere? [See 210 and 216.] (18)

74. State the various grounds on which it is inferred that a high temperature exists in the earth's interior. [See 53 and 54.] (15)

75. Explain the origin of ground-ice, pack-ice, and icebergs. [See 128 and 134.] (15)

76. Describe the several methods by which beds of limestone are now being formed upon the earth's surface. [See 47 and 85.] (15)

77. What conclusions concerning the origin of the physical features of the moon have been deduced from its telescopic appearance? [See 178, &c.] (15)

78. How has the size of the earth been determined? [See 158.] (15)

79. What are the three elements to be observed before the state of the earth's magnetism at any place and time can be determined? [See 34]. (15)

HONOURS EXAMINATIONS.

Instructions.

You are permitted to attempt only four questions, but these may be selected from any part of the paper.

The value attached to each question is the same.

91. State the various methods by which the density of the earth has been determined. What are the results which have been arrived at? Compare the density of the earth with that of the other planets. [See 160 and table 208.]

92. What are the different theories which have been put forward in explanation of the origin of volcanic cones and craters? State the arguments for and against each of these theories. [See 55, &c.]

93. Explain the nature and probable mode of origin of the several different kinds of deposits now being formed in the deepest explored portions of the ocean. [See 85.]

94. State the chief differences which have been observed in the stella spectra, and the conclusions which may be drawn from these differences. [See 214.]

95. Describe the instruments in a self-recording magnetic observatory. [See 219.]

96. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—

(a) The constitution of the sun. [See 210.]

(b) The origin of the ocean currents. [See 88.]

(c) The distribution of temperature on the earth's surface during former periods of its history.

(d) The nature of its liquids occupying minute cavities in the crystals of rocks.

PHYSIOGRAPHY. (1878.)

Examiners—Prof. John W. Judd, F.R.S., and J. Norman Lockyer, Esq., F.R.S.

FIRST STAGE OR ELEMENTARY EXAMINATION.

51. The river Rhone enters the Lake of Geneva as a muddy stream, and leaves it as a perfectly clear one. State the source whence the sediment carried by the river is derived, and what becomes of it. Explain the changes which are being produced in the physical features of the country by the removal and re-deposition of the material carried by the river. [See 94.] (15)

52. What is a "bore"? How are bores produced? Name three rivers which exhibit this phenomenon. [See 182.] (15)

53. How is dew formed? State the conditions of atmosphere which interfere with the formation of dew; and explain how the deposition of dew is checked by these conditions. [See 122.] (15)

54. In what respects do a volcano and a geyser resemble one another, and in what respects do they differ? Name the principal districts on the globe in which geysers are found. [See 55—58.] (15)

55. Name four of the most common minerals which enter into the composition of the earth's crust, and state the elements of which each is composed. [See 45.] (10)

56. Describe the minute structure of a piece of chalk, and show how, by simple experiments, the two oxides of which it is composed may be respectively isolated. [See 44—49.] (10)

57. State the different methods by which the heights of mountains can be determined. [See 107.] (10)

58. Draw a sketch-map of Africa, and indicate upon it the positions of its great lakes, and the courses of its principal rivers. [See maps.] (10)

59. What are isobars? State the causes to which their continual changes in position are due. [See 134.] (10)

60. Describe the mode of origin of icebergs. [See 134.] (10)

61. What are the magnetic poles, and what do you know about their geographical position? [See 32 and 33.] (10)

62. In what parts of the globe are elephants now found? Is there any evidence that they once lived in other areas? and, if so, state the nature of that evidence. [See Eocene and Miocene period.] (10)

SECOND STAGE OR ADVANCED EXAMINATION.

71. Describe the principal methods which have been devised for determining the longitude of a place. [See 171.] (18)
72. State the general facts at present known concerning the temperature of the waters of the ocean. [See 87 for each ocean.] (19)
73. What are the nature and composition of the chief materials ejected from volcanic vents? [See 55 and 61.] (18)
74. Explain the principle on which the sending of storm-warnings from America is based, and state the causes which may prevent these predictions from being fulfilled. [See 120 and 135.] (15)
75. How has it been proved that the earth is not a perfect sphere? [See 159.] (15)
76. State what you know about nutation. [See 166.] (15)
77. What is an "arc of parallel," and an "arc of meridian?" Give examples of both. [See 158.] (15)
78. What are earth currents? [See 26—32.] (15)
79. Compare the chemical constitution of the crust of the earth with that of the sun's atmosphere, comets, and nebulæ. [See 44, 46, and 210, 183, &c.] (15)

HONOURS EXAMINATION.

91. Give an account of the apparatus by means of which observations have been made in the deeper parts of the ocean; and describe the general form of the bed of the Atlantic Ocean. [See 86.]
92. Explain the methods by which the depth of the shock producing an earthquake-wave can be determined. [See 63.]
93. State the chief arguments that have been adduced against the hypothesis that the earth consists of a solid shell with a liquid interior. [See 53 and 54.]
94. Describe the phenomena presented by auroræ, and state what you know concerning the hypotheses which have been put forward to account for their production. [See 36, 218, and 219.]
95. State the facts which have led to the view that meteorological changes, and changes in terrestrial magnetism, are connected with one another. [See 29 to 36 and 186.]
96. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—
(a) The density of the earth. [See 160.]
(b) Double and multiple spectra of the same elementary body. [See 205.]
(c) The measurement of the sun's distance. [See 174.]
(d) The cause of the movement of bubbles in the liquids enclosed in minute cavities of the crystals of rocks.
(e) The existence of man during or before the glacial epoch.

The first numbers in brackets are the paragraphs where the information may be found. The other number is its value at the examination.

PHYSIOGRAPHY. (1879.)

FIRST STAGE OR ELEMENTARY EXAMINATION.

1. What is the number of known chemical elements? Name the six elements which occur in greatest abundance in the crust of the earth. State the condition in which the metallic elements generally exist in that crust. [See 39 and 45.] (15)
2. When water is left standing in a vessel out of doors, it gradually disappears. State what becomes of the water, and under what conditions of atmosphere it will disappear most rapidly. [See 121 and 122.] (15)
3. State what rock-constituents are carried by rivers to the sea in suspension and solution respectively: and describe what becomes of those materials when they reach the sea. [See 94.] (15)

4. How do you explain the fact that fringing coral reefs generally occur in volcanic areas. and atolls, encircling-reefs and barrier-reefs, in non-volcanic areas? [See 63 and 64.] (11)

5. Describe the principle of the construction of the mercurial barometer. [See 103.] (11)

6. What are moraines? Name the different kinds and describe the manner in which they are formed. [See 130.] (11)

7. Draw a sketch map of the Mediterranean Sea, showing the positions of the chief islands. [See map.] (11)

8. Name the minerals which occur in a piece of granite, and describe their chemical composition. [See 45.] (11)

9. What is the chemical composition of a piece of common coal, and how does it differ in composition from peat on the one hand and anthracite on the other? [See 49.] (11)

10. What is the cause of the noise heard during thunderstorms? [See 30.] (11)

11. Describe some of the forms found in snowflakes, and explain their origin. [See 128.] (11)

12. What evidence have we that lions and tigers once lived in this country? [See 65.] (11)

SECOND STAGE OR ADVANCED EXAMINATION.

1. Draw the earth, as seen from the sun, at the two solstices and equinoxes, showing the direction of its axis and the positions of the north and south poles. (13)

2. Describe the trade winds, and state the causes to which they are due. [See 116 and 115]. (18)

3. State the different kinds of evidence from which it is inferred that certain parts of the earth are being upheaved, and others are subsiding. [See 63 and 64.] (19)

4. Explain the cause of the difference between the climates of London and Moscow. [See 134.] (15)

5. Name the several gases of which the atmosphere is composed, the proportions in which they are present, and the manner in which they are united with one another. [See 99.] (15)

6. What proofs have we of the existence of a high temperature within the earth? [See 53.] (15)

7. Describe a transit-circle and its uses. [See 172.] (15)

8. How does a dipping needle behave at the magnetic poles, and why? [See 32—34.] (15)

9. What terrestrial phenomena seem to be connected with the number of spots seen on the sun at different times? [See 26 and 35.] (15)

HONOURS EXAMINATION.

1. Explain the construction of any forms of seismometers or seismographs with which you are acquainted.

2. Mention the several theories which have been advanced to account for the existence of the great rock-basins occupied by lakes; and state the arguments for and against each of these theories. [See 97.]

3. Describe the composition of the different classes of meteorites and compare it with that of the earth's crust. [See 199 and 200.]

4. State what you know about the spectrum of Sirius and Uranus respectively; and the conclusions which have been drawn from the observations. [See 214.]

5. How has the connection between luminous meteors and comets been established, and what is the nature of the connections? [See 199 and 200.]

6. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects :—

(a) The distance of the sun as determined by observations of Mars at opposition. [See 174.]
(b) The spectrum of oxygen.
(c) The nature of volcanic products during the older Palæozoic periods.
(d) The existence of great continental "ice-sheets."

PHYSIOGRAPHY. (1880.)

FIRST STAGE OR ELEMENTARY EXAMINATION.

1. Name the binary compounds which are united to form a piece of limestone. State how these may be separated from one another, and describe the characters presented by each of them. What elements are present in these binary compounds, and what is the general character of each of these elements? [See 41, 44, and 39.]

2. Describe the construction and use of a thermometer, and explain the methods by which thermometers are graduated. [See 112.] (15)

3. Why is the south-west wind in this country usually accompanied by rain, while the east wind brings dry weather? [See 118 and 125.]

6. What are fiords? and how do you suppose them to have been formed? [See 91.]

7. Describe the phenomena called *roches moutonnées*, and explain how they are formed? [See 132.] (11)

8. Draw a sketch map of Hindostan, showing the position of its great mountain ranges and rivers. (N.B.—Names must be given.) [See Maps, &c.] (11)

9. Name six of the minerals which occur most commonly in igneous rocks, and describe their composition. [See 45—51.] (11)

10. How is kaolin derived from granite? Describe the several stages of the process. [See 45.] (11)

11. What is the cause of the interval which elapses between a flash of lightning and its accompanying thunderclap? If this interval, in any particular case, were found to be 11 seconds, what inference would you draw from the fact? (See 110.) (11)

12. What is meant by the statement that certain forms of life have become extinct? State some of the causes which have brought about the extinction of animals, and name any animals which have become extinct since the appearance of man. [See 64.] (11)

SECOND STAGE OR ADVANCED EXAMINATION.

1. State what you know about the apparent movements of the stars and the causes which give rise to them. [See 202.] (23)

2. Explain the methods by which the quantity of material carried down by rivers in suspension and solution respectively, can be determined. How may this be made to gauge the rate of subaerial denudation within the river basin? [See 94.] (23)

3. Describe the monsoons; stating the periods at which they blow, the countries in which they are felt, and the causes to which they are due. [See 117 and 116.] (18)

4. Explain the action of plants and animals upon the constituents of the atmosphere. [See 136 and 137.] (18)

5. Describe the principle of the construction of the aneroid barometer. [See 104.] (18)

6. What are the views at present concerning the nature of Saturn's rings, and what are the facts on which these views are based? [See 195.] (18)

7. Explain the terms "dispersion" and "minimum-deviation," as applied to a ray of light. [See 108, 147, &c.] (18)

8. How is the intensity of terrestrial magnetism at any place of observation determined? (See 33 and 34.] (18)

HONOURS EXAMINATION.

1. Explain the several theories which have been proposed to account for the spasmodic action of geysers, and state the arguments for and against each of these theories. [See 58 and 59.]
2. Explain by the aid of a sketch-map the course of the tidal wave around the British Islands. [See map.]
3. State what you know about the spectrum of *a Lyræ* and the sun respectively, and the conclusions which have been drawn from the observations. [See 210 and 211.]
4. State the probable climatic conditions of Mars and Jupiter. [See 192.]
5. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—
(*a*) The nature of the sun's corona. [See 184, 210, &c.]
(*b*) The microscopic character of the sedimentary rocks.

PHYSIOGRAPHY. (1881.)

FIRST STAGE OR ELEMENTARY EXAMINATION.

1. What chemical elements are present in water? How can water be separated into its elements, and how can these elements be made to re-unite to form water? [See 47.] (15)
2. Why does ice usually form on the surface of water, and under what circumstances is it occasionally formed at the bottom of a piece of water? [See 45 and 125.] (15)
3. On what grounds is it believed that a high temperature exists in the deeper part of the earth's crust? [See 53 and 54.] (15)
4. Explain the fact that no dew is found upon the ground after a cloudy or windy night. [See 122 and 121.] (11)
5. Describe a raised-beach, and state what inference you would draw from its existence. [See 63a.] (11)
6. Explain the nature and cause of the difference between continental and insular climates. [See 134.] (11)
7. Draw a sketch map of Africa, marking on it the positions of the chief rivers and lakes. (N.B.—Names must be given.) [See Maps.] (11)
8. State the causes which may give rise to an excessive rainfall in a district, illustrating your remarks by examples. [See 125.] (11)
9. Explain the formation of coal. [See 49.] (11)
10. In what respect do slate and shale respectively differ from clay? [See 49.] (11)
11. What is meant by the snow-line, and on what conditions does the height of the snow-line on different mountain chains depend? [See 128.] (11)
12. Explain what is meant by the "geographical range" of a species of animal or plant. [See 138, &c.]

SECOND OR ADVANCED STAGE.

1. Describe the changes which will take place in the volume of a pound of water as its temperature is raised from 0°F. to 300°F. [See 45.]
2. State what you know about Kepler's laws. [See 175.] (23)
3. What is the cause of the low temperature which prevails at the bottom of the deep oceans? [See 87.] (18)
4. What are hygrometers? Explain the construction and mode of use of some form of hygrometer. [See 123, &c.)
5. Describe the characteristic features of the different kinds of volcanic cones, known as scoria-cones, tufa-cones, lava-cones, and compound-cones. [See 55—58.] (18)
6. How are the colours produced in the rainbow? [See 109.] (18)
7. Explain the equation of time. [See 163.] (18)
8. What are the principal phenomena observed in a total eclipse of the sun? [See 181.] (18)

HONOURS EXAMINATION.

1. State and discuss the various objections which have been raised against the hypothesis that the earth consists of a solid outer shell with a fluid nucleus. [See 53.]
2. In what respects does globigerina-ooze resemble chalk, and in what respect does it differ from that rock? [See 88, &c.]
3. What are the methods generally adopted in measuring a base-line for a geodetical survey? [See 159.]
4. State what is known about the satellites of Mars. [See 198.]
5. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects :—

(a) The artificial formation of crystallised minerals.
(b) The spectra of the fixed stars. [See 207 and 214.]

PHYSIOGRAPHY. (1882.)

1. What chemical elements and what compound bodies are usually present in the atmosphere? State the proportions in which these elements and compounds occur. [See 92.]
2. Describe land and sea breezes, and state how they are produced. [See 117 (2).]
3. What is the cause of the long days and nights of the Polar regions? [See 133.]
4. How are snow and hail formed? [See 128 and 129.]
5. What are isothermal lines? Explain why it is that isothermal lines do not coincide with the parallels of latitude. [See 134 and 135.]
6. How has it been proved that glaciers move, and what facts do you know of glacier movement? [See 130.]
7. Draw a sketch map of South America, indicating upon it the positions of the chief mountain ranges and rivers. (N.B.—Names must be given.)
8. What is meant by the rainfall of a place, and how is it measured? [See 125.]
9. Describe the chemical constitution and microscopic structure of a piece of chalk. [See 41 and 45 (2).]
10. What are volcanic bombs, and how are they formed? [See 54.]
11. Give a short account of the organism by which coral-reefs are formed. [See 49 (2).]
12. What is meant by the fauna and flora of a place? [See 138—140.]

SECOND STAGE.

21. How is the longitude of a place on land determined astronomically? [See 171 and 172.]
22. What are cyclones and anticyclones, and how are they produced? [See 120.]
23. How would you explain the low temperature which prevails in the higher regions of the atmosphere? [See 113.]
24. How has the rate of increase of temperature in going downwards in the earth's crust been determined, and what are the chief sources of error in such observations? [See 54.]
25. What is a seismometer? Describe some form of seismometer with which you are acquainted.
26. State what you know concerning the chemical and physical constitution of stars (excluding the sun). [See 203, 207, 214.]
27. Draw the apparent form of the moon at the first and third quarters, and give diagrams showing the relative positions of the moon, earth, and sun, at these periods of the lunar month. [See 177, &c.]
28. What is the synodic period of a planet? [See 177 and 190, &c.]

HONOURS EXAMINATION.

41. If you had the opportunity of visiting a country recently devastated by a great earthquake, state the nature of the observations you would make, and the conclusions you would be able to deduce from such observations.

42. On what grounds has it been argued that the positions of the great oceanic depressions have been permanent during past geological times?

43. State what you know about the surface of the planet Mars. [See 192.]

44. What is known regarding the chemical nature of comets? [See 200 and 201.]

45. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—

(a) The tides. *(b)* The origin and nature of fogs.

PHYSIOGRAPHY. (1883.)

FIRST STAGE.

1. Describe the structure of a snowflake. Why does snow differ from ice? [See 128.]

2. What are the causes of the variations of pressure of the atmosphere? [See 100 and 103.]

3. How can you prove that the waters of a river remove materials in a state of solution from the land, and how can the quantity of materials so removed be estimated? [See 94.]

4. In what respects does the water of the sea differ from that of rivers and lakes? [See 82, 84, &c.]

5. Give a drawing of a rain-gauge, and state the principle of its construction. [See 126.]

6. What materials are taken from the atmosphere by plants, and what becomes of those materials? [See 136.]

7. What are landslips? How are they caused? [See 92.]

8. Give a drawing showing the internal structure of a cinder or scoria-cone.

9. Draw a sketch-map of Australia, showing the position of the chief mountain ranges and rivers.

10. What is the cause of the great cold which prevails in the Polar regions?

11. What is globigerina-ooze, and where is it found? [See 85.]

12. What is meant by "the extinction of a species?" Give examples of three species of extinct animals. [See 64.]

SECOND STAGE.

1. What are the chief instruments employed at a meteorological station, and what is the nature of the observations made with each of these instruments? [See 134.]

2. What is the difference between a refracting and a reflecting telescope? Describe the construction of both? [See 154.]

3. Describe observations by which the rate of movement of glaciers has been determined, and state the results which have been arrived at by these observations. [See 130.]

4. What are the chief animals and plants which separate calcic carbonate (carbonate of lime) and silica from a state of solution in the waters of the sea? [See 85.]

5. What is meant by the precession of the equinoxes? [See 167.]

6. Describe the different methods of determining the distance of the sun from the earth. [See 174, 175, &c.]

7. In what way does the spectroscope enable us to determine the composition of the heavenly bodies? [See 210 and 211.]

HONOURS EXAMINATION.

1. Compare the composition of meteorites with that of the earth's crust. [See 200 and 201.]

2. What are geo-isothermal lines, on what data are they drawn, and what facts have been determined concerning their relations to different districts? [See 134.]

3. State what you know about sun spots, and explain the terms Corona, Chromosphere, Photosphere, Faculæ. [See 210, 211, and 212.]

4. When observing with an ordinary spectroscope, why do we get bright or dark lines, as the case may be, across the spectrum? [See 210 and 211.]

5. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—

(*a*) The origin of crystalline sands.
(*b*) Comets. [See 199 and 200.]

PHYSIOGRAPHY. (1884.)

FIRST STAGE OR ELEMENTARY EXAMINATION

1. What chemical elements are found in pure water? What is the nature of those elements? In what proportion do they exist in water, and in what way may these elements be made to combine? [See 46.] (15)

2. What is a glacier? Where do its materials come from? What becomes of its materials? [See 130.] (15)

3. Of what are volcanoes composed? Why have they usually a conical shape? How have their "craters" been formed? [See 55.] (15)

4. Under what conditions may ice be formed at the bottom of a piece of water? [See 129.] (11)

5. Explain the causes of the difference of climate on the east and west coasts of Great Britain. [See 134, 118, &c.] (11)

6. How are the direction and force of the wind measured? [See 115.] (11)

7. Draw a sketch-map of Africa, inserting on it the chief mountains, rivers, and lakes. (N.B.—Names must be given.) (11)

8. Describe the mariner's compass. [See 33.] (11)

9. Give the names of six of the most common minerals which occur in igneous rocks. [See 45—51.] (11)

10. What is silica? What name is given to silica in its crystallised form? With what substances is silica found combined in the earth's crust? [See 41 and 42.] (11)

11. Why is the heat so great in the equatorial regions of the globe? [See 108—113.] (11)

1 . Give the names of the chemical elements which make up the greater portion of plants and animals. What compound bodies are most commonly given off during the decay of animal and vegetable substances? [See 136.] (11)

SECOND STAGE OR ADVANCED EXAMINATION.

21. How have the shape and size of the earth been determined? [See 158, 159, &c.] (23)

22. Explain the principle and mode of construction of the mercurial barometer. [See 103.] (23)

23. Explain the use of the telegraph in connection with meteorological observations. [See 135 and 119.] (18)

24. How is the degree of humidity of the atmosphere best determined? [See 123.] (18)

25. State the chemical changes which take place during the conversion of vegetable tissues into coal. [See 49.] (18)

26. Describe the construction of the achromatic object-glass. [See 153.] (18)

27. What are the chief elements of a planet's orbit? [See 157.] (18)

28. Compare the chemical constitution of the crust of the earth with that of the atmosphere of the sun. [See 183—210.] (18)

HONOURS EXAMINATION.

41. State the chief arguments for and against the hypothesis that the earth is solid to its centre. [See 54.]
42. How has it been proved that carbonic anhydride is present in a liquid condition in the cavities of minerals in some rocks?
43. State what you know about the tides. [See 182.]
44. How does the constant of aberration enable us to determine the sun's distance? [See 148.]
45. Give an account of the results which have been obtained by recent researches in connection with the following subjects :—

(a) The chemistry of the stars. [See 207—214 and 217.]

(b) The occurrence of falls of dust of meteoric origin upon the earth's surface. [See 199, 200, 201.]

SET AT THE CHRISTMAS EXAMINATIONS FOR TEACHERS.

PHYSIOGRAPHY. (Christmas, 1878.)

Examiners—Prof. John W. Judd, F.R.S., and J. Norman Lockyer, Esq., F.R.S.

General Instructions.

If the rules are not attended to, the paper will be cancelled.

Put the number of the question before your answer.

You are to confine your answers strictly to the questions proposed.

Your name is not given to the Examiners, and you are forbidden to write to them about your answers.

You are permitted to attempt only six of the following questions, and the three which stand first upon the paper must be included among these.

Three hours allowed for this paper.

1. State how you would explain to a class the mode of the formation of dew, and describe any illustrations you would employ in order to make the matter clear to the minds of your scholars. [See 122.] [18]
2. Explain by the aid of a diagram the internal structure of volcanic cinder cones, and state the causes to which that structure is due. [See 55.] (18)
3. Imagine that you are explaining to a class the cause of the seasons. Write down what you would say, and give the diagrams you would make. [See 164 and 165.] (19)
4. In what portions of the globe are rainless areas situated? State the causes of the dryness of climate in each case. [See 127.] (15)
5. Explain the agencies by which a piece of granite is disintegrated, and enumerate the products of this disintegrating action. [See 44 and 45.] (16)
6. What are the principal salts dissolved in sea water? Explain what becomes of the various materials carried in a state of solution by rivers to the ocean. [See 94, 82, 84, &c.] (15)
7. State how the distance of the moon from the earth has been determined. [See 173.] (15)
8. Describe the construction and mode of use of the spectroscope. State what you know about the spectrum of sodium, of chlorine, and of the sun. [See 155, 209, 210, 211.] (15)
9. What is a dip-circle or dipping needle? How is it used, and what has it taught us? [See 33 and 34.] (15)

PHYSIOGRAPHY. (Christmas, 1879.)

General Instructions.—See preceding Paper.

1. Give notes for a lesson to a senior class "On the evidence which coral reefs afford of great movements taking place in portions of the earth's crust." [See 49 (2).] (15)
2. Enumerate the varieties of ice-masses which are found in the Arctic and Antarctic regions, and explain the mode of origin of each. [See 134, 135, and 136.] (15)
3. Write down what you would say, and give the diagrams you would make, in explaining the phases of the moon. [See 178.] (15)
4. Describe the phenomena presented by the land and sea breezes, and state the causes to which they are due. [See 117.]
5. State what you know about the composition of white light, and show (1) how this may be studied by simple experiments and (2) its bearing upon the composition of stars. [See 209a, 210, &c.] (12)
6. Describe the construction of a mercurial barometer, and explain its mode of action. Why is mercury the fluid usually employed for barometric purposes? [See 103.] (15)
7. Does the mariner's compass always point true north and south? If not, why not? and where is the greatest variation at the present time? [See 33 and 34.] (15)
8. State what gases are given off during the conversion of vegetable tissue into peat, coal, and anthracite; and describe the differences in composition of these four substances. [See 49.] (20
9. State how the distance of the earth from the sun has been determined by observation of Mars at opposition. [See 174.] (20)

PHYSIOGRAPHY. (Christmas, 1880.)

General Instructions.—See Paper for 1878.

1. Describe a series of simple experiments, not involving the use of any costly apparatus, by means of which you would illustrate to a class of children the properties and composition of the atmosphere. [See 99.] (25)
2. Write down what you would say and give the diagrams you would make in explaining to a class the causes of the variation of the length of the day in the different seasons of the year. [See 164 and 165.] (25)
3. What are the chief facts known concerning the nature of the movement of glaciers, and the rate at which this movement takes place? Describe the observations by which these facts have been discovered. [See 130.] (20)
4. What is the equation of time and what is mean time? [See 163.] (20)
5. Give a short account of the principal kinds of organisms whose remains go to build up limestone-rocks. [See 85.] (15)
6. What facts relating to terrestrial magnetism are given in a magnetic chart of the earth's surface? (15)
7. Explain the nature of earthquakes and describe the chief phenomena which accompany them. [See 60.] (15)
8. What has the spectroscope taught us concerning the chemical and physical constitution of the atmosphere of the sun? [See 209 and 210.] (15)

PHYSIOGRAPHY. (Christmas, 1883.)

1. State the different movements of the earth. [See 157, 163, and 164.] (25)
2. Give notes for a lesson to a senior class on "The Chemical Constitution of the Atmosphere," describing the simple experiments by which you would illustrate the lesson. [See 99.] (25)

3. How has the vertical distribution of temperature in the waters of the ocean been determined? State the chief facts which are now known on this subject. [See 87 and 88.] (20)
4. How has the density of the earth been determined? [See 160.] (20)
5. Give the names of the minerals which make up the rocks called "granite," "trachyte," and "basalt;" and state what you know concerning the chemical composition of each of these rocks. [See 44, 45, &c.] (15)
6. State, as simply as you can, what is the real nature of an earthquake. [See 60.] (15)
7. Point out the errors in the following statement:—"Coral reefs are built by the persevering labours of the ingenious coral insect." [See 49 (3).] (15)
8. Describe how the position of a star is defined. [See 172.] (15)

PHYSIOGRAPHY. (Christmas, 1884.)

1. Give notes for a lesson to a senior class on the effects of changes o temperature upon water, stating the simple experiments you would employ [See 44.] (25)
2. What causes an eclipse of the moon? Why are not such eclipses always total? (24)
3. What is meant by denudation? How would you prove to your class that denudation is taking place at the present time? [See 131, &c.] (20)
4. Describe the construction of both a reflecting and a refracting telescope. [See 154.] (20)
5. State what you know concerning the composition of silica and silicates, and the part these substances play in the constitution of the globe. [See 41 and 42.] (15)
6. What is meant by the aberration of light? [See 148.] (15)
7. Describe the construction of the barometer, and explain its use. [See 103.] (15)
8. What is the theory of the formation of Saturn's rings? [See 195.] (15)

INDEX.

PAGE.
Aberration, Chromatic 168
Aberration of Light 165
Acid 17, 22, 32
  Carbonic.... 17, 32, 34, 142, 151
Acceleration 14
Achromatic Object Glass 168
Aerolites 218
Age of the Earth 67
Aldebaran 222, 224
Algol 222
Alkali 33
Alumina 41, 36
Anemometer 125, 149
Anemoscope 125
Angle of Incidence 166
  Emergence 60
Animals 151
  Distribution of 157
Annual Motion 183
Antarctic Regions 144
Anticyclones 130
Apsides 186
Aqueous Rocks 40
  Vapour 132, 134
Arctic Regions 144
  Expedition 145
Aries, First Point of 190, 197
Asteroids 210
Atlantic Ocean 72, 97
Atmosphere 20, 21, 115
  Composition of 115
  Pressure of 117
  Height of 118
  In relation with Light 121
  Effect of Animals and Plants on ... 151
Atomicity 30
Atomic Weight 27
Atoms 16, 17, 27
Attraction 12, 13
  of Cohesion 15
Auroræ 20, 22, 25, 238
Avalanches 140

Barometer 118, 148
  Aneroid 118
  Self-Registering 120

PAGE
Barrier Reef 63
Bilfar 239
Binary Compounds 31, 34
Biology 152
Bode's Law 207
Bore 201
Boulders 145
Breakers 97
Breccia 41

Cainozoic Period 64
Calcite 34
Calcium 29, 31
Cañons 86, 106
Carbon 17
Carbonaceous Group 44
Carbonic Acid.... 17, 32, 34, 142, 151
Chalk 31, 32, 34, 142, 151
Challenger Expedition.. 87, 89, 92, 93
Chemical Affinity 16
  Action 26
  Elements 26, 28, 29
Chemically-formed Rocks 46
Chromosphere 202, 232
Climate 146, 152, 187
  Representation of 147, 148
Clouds 134
Coal 45
Cohesion 15, 17
Comets 216
Compounds—Chemical 27, 33
  Decomposition of 33
Conglomerate 41
Conical Projection 179
Condensation 132, 205
Conduction 17
Constant of Aberration 165
Convection 17
Coral 31, 43
Corallaria 44
Corona 202, 234
Coseismal Circles 60
Cretaceous System 64
Crust of the Earth.... 40, 61, 102, 141
Currents 88, 96
Cyclones 129, 130, 206

PAGE.
- Day and Night 184, 145
- Declination 23, 24, 25, 188, 190
- Declimometer 239
- Definitions 68, 187
- Deltas 108
- Density of Earth 177
  - Planets 208
  - Ocean 89
- Denudation 141, 142
- Depth of Ocean 89, 93
- Devonian System 64
- Dew 182
- Diatoms 90, 92
- Diatom Ooze 92
- Diffusion of Gases 117
- Distance of Heavenly Bodies .. 191
- Diurnal Motion of the Earth 182
- Double Stars 228

- Earth 174
  - Age of 67
  - Internal heat of 51
  - Interior of 52
  - Density 52, 177
  - Size of 174
  - Weight 179
  - Motions of 182
  - Crust of 40, 61
  - Growth of 219
- Earth Currents 20
- Earthquakes 58
  - Causes of 59
  - Mallet on 60
- Eccentricity of Earth's Orbit 186
- Eclipses 129
- Ecliptic 68, 184
- Electrical Disturbances 20
- Electricity 19, 23
  - Atmosphere 20
  - Accumulation of 20, 21
- Elements, Chemical 26, 28, 29
  - Magnetic 24
- Energy 18, 19
  - Attractive 18
  - Volcanic 56
- Eocene System 66
- Equation of Time 185
- Ether 164
- Evaporation 182, 205
- Expansion 18, 19
  - Coefficient of 18
- Extinct Animals 64, 66
  - Volcanoes 56

- Faculæ 203
- Falling Stars 218
- Fauna 68
- Field Ice 145
- Flint 44
- Fog 188
- Foraminifera 63
- Formations, Geological 64
- Force 7
- Forces, Composition of 9
  - Resolution 9
  - Parallelogram of 9, 10
  - Polygon of 11
  - Resultant of 11
- Fringing Reefs 62
- Fraunhofer lines 227
- Fumeroles 56

- Geodetical Surveys 175
- Geological Systems 64
- Geology 40
- Geysers 56, 57
- Glacial Period 67, 187
- Glaciers 140, 143
- Globigerina 90
- Globular Projection 179
- Gneiss 35, 48
- Granite 34, 48
- Granules, Sun's Surface 204
- Gravitation 12
- Gravity, Terrestrial 13
- Gregorian Telescopes 169
- Gulf Stream 99, 147
- Hail 189
- Heat 15, 17, 124
- Heavenly Bodies, Distance of .. 191
- Herschelian Telescope 169
- Hoar Frost 188
- Hot Springs 56, 104
- Hottest Region 149
- Huxley's Classification 162
- Hygrometer 188
- Hypsometrical Zones 154, 156

- Ice 140
  - Field 145
  - Ground 87, 140
- Icebergs 145
- Icegrains, Sun's Surface 87, 140
- Igneous Rocks 48
- Inclination of Earth's Axis 185
  - Magnetic Needle 24, 25
- Internal Heat of the Earth 51
- Isobaric Lines 148
- Isocheimal 147
- Isoclinals 24
- Isothermal 148

- Jupiter 211

PAGE.
Jupiter's Satellites 215
Jurassic System 64, 65

Kaolin 34, 41
Kepler's Laws.................. 172

Lakes...................... 103, 114
  Origin of 114, 144
  Uses of 115
Land—Distribution of.......... 72
  Configuration of............ 73
  Breezes 127
Latitude.................... 68, 188
Laurentian System 64
Lenses 167
Libration 196
Life............................ 152
  in the Ocean Depths......... 92
  Animal 151
  Plant 151
Light 121, 164
  Velocity of 164
Lightning...................... 21
  Expedition 92
Lime 31, 34
Limestones...............31, 34, 43
Limiting Angle 166
Longitude..................... 189
Lunation 196

Magnet, The Earth a 23
Magnetic Declination 23
  Variation 23
  Instruments 239
  Storms 25, 206
  Poles 22, 23
Magnetism 22, 23, 238
  Unit of 25
Magnetometer 239
Man 161
Map Projections................ 179
Mariner's Compass 23
Mars.........................210, 215
  Unit of 8
Matter 12
Mercury 209
Meridian 68
Metamorphic Rocks 47
Meteorology.................... 148
Meteors 218
Minerals, Composition of 35, 36
Miocene Period 64
Mirage 122
Motion—Laws................. 188
  Recessional 235
  Precessional............... 186

PAGE.
Monsoons 128
Moon 195
  Phases of 196
  Surface 197
Mountains 75
  Systems.................... 77
  Lunar...................... 198
Movements of the Earth's Crust 61, 63
  „ „ Ocean 96

Neap Tides 200
Nebulæ 225, 226
Nebular Hypothesis 226, 240
Negro Race 161
Neptune 274
Newtonian Telescope 169
Night 184, 145
Nodes 69, 173
November Showers 218
Nutation 185

Oceans 86, 101
  Density.................... 86
  Depth...................... 89
  Temperature 94
  Composition of 88
  Movements of.............. 96
  Colour 89
  Bottom of.................. 90
Ocean Deposits 90
  Currents 97
Oceanic Circulation 95
  Theories of................95, 96
Orbits of Planets 171, 173, 182
Organically-formed Rocks...... 43
Oxygen............26, 28, 29, 37, 151
Ozone.......................... 22

Pack Ice 145
Parallax of Planets 184
Palæozoic Period 6
Peat 45
Periodical Winds 126
Permian System 64, 65
Pendulum 8, 178
Photosphere.................... 202
Physics 7
Plains....................82, 84, 128
Planets 170, 207
  Parallax of 195
  Motion of 171
  Atmospheres of 209
  Orbit, Elements of.......... 173
Plane of the Ecliptic............ 184
Plants 151
  Distribution of 153
Pleiades....................... 222

PAGE.
Pliocene Formation 64
Plutonic Rocks 50
Polar Winds.................... 126
Polyps 44
Population of Globe 163
Post-tertiary System 64
Precessional Motion 186
Pressure of Atmosphere 117
  at Bottom of Sea 94
  How Found 94
Prisms 167
Projections, Map 179
Propagation of Light 164
Puna Winds.................... 128

Quartz........................31, 48

Races 162
Radiation 17
Radiant Point.................. 218
Radiolaria 90
Rain...................... 35, 146
  Gauge 146, 148
Rainbow 122
Rainless Districts 137
Reefs 62
Red Clay Deposits 90, 92
Reflection...................... 165
Refraction 16
Relative Age of Strata.......... 63
Reversing Layer................ 231
Revolution of Apsides 186
Rice Grains—Sun's Surface 204
Right Ascension................ 190
Rivers 92, 105
  Agents of Denudation ..141, 143
  Work of 106, 143
  Velocity of 106
River Systems.................. 109
Rocks.......................... 26
  Composition of 33, 36
  Aqueous 40
Roches Moutonnées 143

Salts of the Ocean 86, 88
Sandstone 41
Satellites 214
Saturn 212, 216, 226
Saturn's Rings 213
Sea-breezes 127
Sea's Action on Earth's Crust .. 102
Seas, Inland.................... 101
Seasons 185
Sedimentary Rocks 40
Seismic Vertical 60
  Force 60

PAGE.
Shale 41
Shingle 40, 42
Silica 31, 36
Silicates 32, 33, 36
Silurian System 64
Sirius 222, 225, 234, 236
Snow 137
  Red.......................... 145
Snowline 138
Soil, Surface 42
Solar Disturbances 206
  Cause of 206
  System 207
  Microscope 170
  Spectrum 228
Sound 122
Sounding, Methods of 93
Salfataras 56
Spectra of Stars, &c. 224, 225
Spectroscope 170, 203, 229, 232
Spectrum Analysis 227
Spots, Sun 20, 25, 203, 206, 232
Springs 103
  Hot 56, 104
  Intermittent 104
Stars 220
  Distance of................ 221
  Magnitude 221
  Colour of................224, 234
  Variable 222
  Spectra of 222, 234
  Double 223
Star Clusters.................. 225
Storms 129, 189
  Magnetic 25, 206
Stratified Rocks................ 40
Subsidence 61
Sun 201
  Composition of 203
  Constitution of 230
  Size of 201
  Density of.................. 201
  Apparent Motion of 183
  Distance of 192
  Spots 20, 25, 203, 206, 232
Sun's Condition 231
  Motion in Space............ 202
Surface Soil 42
Synodical Period 196
Surveys, Geodetical 175

Tablelands 82
Table of Minerals (rock-forming) 36
Telescope 168
Temperature 123
  Oceans 94
  Planets 209

PAGE.
Terrestrial Magnetism 23
Tertiary System 64
Theodolite 175
Thermal Springs 56, 104
Thermometer 124, 148
  Protected 94
  Maximum 124
  Minimum 124
Thunder 22
Tidal Waves 200
Tides 200
Trade Winds 126
Transit Instrument 190
  of Venus 191, 193
Triassic System 64
Trilobites 64, 66
Twilight 122, 123, 145

Unit of Time 7
Upheavals 61
Uranus 218

Valleys 86
Vapour 116, 119, 132
Variable Stars 222, 235
  Winds 128
Vegetable Products 156
Vegetation, Marine 155
Velocity 11

PAGE.
Velocity of Light 164
  of Rivers 106
Venus 209
  Transit of 191, 193
Viga 225
Volcanic Rocks 48
  Mountains 55
Volcanoes 53
  Distribution of 54
  Extinct 56

Water 37
  Composition of 37
  Expansion 38
  Specific heat of 39
  Freezing point 38, 37
Waves 96
  Tidal 200
  Light 164
Weather 150
  Forecasts 150
Winds 124
  Force of 125
  Direction 125

Zenith 188
Zodiacal Light 234
Zones 69
Zones, Hypsometrical 154, 156

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